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Contract Number DAAA15-87-0095

Historical Background and Development of the Surface Water Element

WATER YEAR 1975 to WATER YEAR 1989

December 1992

R.L. STOLLAR & ASSOCIATES, INC.

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LIST OF ACRONYMS AND ABBREVIATIONS

Analytes and Analyte Groups

ac-ft	acre feet
ALDRN	Aldrin
AMCCOM	Armament, Munitions, and Chemical Command
AS	Arsenic
ATZ	Atrazine
BCHPD	Bicyclo[2,2,1]hepta-2,5-diene
BTEX	Benzene, Toluene, Ethlybenzene, Xylene
BTZ	Benzothiazole
C6H6	Benzene
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
cfs	cubic feet per second
CH2CL2	Methylene chloride
CHCL3	Chloroform
CLC_6H_5	Chlorobenzene
CL6CP	Hexachlorocyclopentadiene
CLDAN	Chlordane
CMP	Comprehensive Monitoring Program
CPMS	p-Chlorophenylmethyl sulfide
CPMSO	p-Chlorophenylmethyl sulfoxide
CPMSO2	p-Chlorophenylmethyl sulfone
CO_3^{-2}	carbonate
CR	Chromium
CRL	Certified Reporting Limits
CU	Copper
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
DDVP	Vapona
DIMP	Diisopropylmethyl phosphonate
DITH	Dithiane
DLDRN	Dieldrin
DMMP	Dimethylmethyl phosphonate
DPA	D.P. Associates
ENDRN	Endrin
EPA	Environmental Protection Agency
ETC6H5	Ethylbenzene

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

Analytes and Analyte Groups

F	Fluoride
FY	Fiscal Year
GB	Sarin/isopropylmethane fluorophosphonate
GC/MS	Gas Chromatograph/Mass Spectrometry
gpd	gallons per day
gpm	gallons per minute
H	Levinstein mustard
HCO_3^-	bicarbonate
HG	mercury
ICP	Inductively Coupled Plasma
IRA	Interim Response Action
IRDMIS	Installation Restoration Data Management Information System
ISODR	Isodrin
ISP	Initial Screening Program
LOQ	Limit of Qualification
MEC6H5	Toluene
MIBK	methylisobutyl ketone
MLTHN	malathion
mm	millimeter
MOA	Memorandum of Agreement
msl	mean sea level
NCP	National Contingency Plan
OXAT	1,4-oxathiane
PB	lead
PPDDE	2,2-bis(para-chlorophenyl)-1,1-dichloroethene
PPDDT	2,2-bis(para-chlorophenyl)-1,1,1-trichloroethane
PRTHN	Parathion
QA/QC	Quality Assurance/Quality Control
RCI	Resource Consultants, Inc.
RI/FS	Remedial Investigation/Feasibility Study
RMA	Rocky Mountain Arsenal
RMAL	Rocky Mountain Analytical Laboratory
rpd	relative percent difference
SARs	Study Area Reports
sq mi	square miles

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

Analytes and Analyte Groups

STP	sewage treatment plant
SUPONA	Supona
TBM	Temporary Bench Marks
TCDHD	Tri-County District Health Department
TCLEE	tetrachloroethylene/tetrachloroethene
TRCLE	trichloroethylene/trichloroethene
TSS	total suspended solids
USATHMA	United States Army Toxic and Hazardous Materials Agency
USGS	United States Geological Survey
UDMS	User Data Management System
VOA	volatile organic analysis
VOH	volatile organohalogen
WRI	Water Remedial Investigation
WRIR	Water Remedial Investigation Report
WY	Water Year
XYLEN	o- and p-xylenes
ZN	zinc
11DCE	1,1-dichloroethylene/1,1-dichloroethene
12DCE	1,2-dichlororethylenes (cis and trans isomers)
12DCLE	1,2-dichlororethane
112TCE	1,1,2-trichloroethane

EXECUTIVE SUMMARY

This report documents the development of the surface-water monitoring program at the Rocky Mountain Arsenal (RMA) from 1975 through fiscal year (FY) 1989. During the last 2 years of this period, (FY88 and FY89), the ongoing Comprehensive Monitoring Program (CMP) was in place. Prior to FY88 (pre-CMP), numerous contractors conducted studies and collected surface-water quantity and quality data.

Background

RMA, located about 6 miles northeast of downtown Denver, contains about 27 square miles in Adams County, Colorado. Land use was agricultural before RMA was built in 1942. Chemical and incendiary weapons were produced from 1942 to 1946, and chemical agents were again produced from 1953 to 1957. Munition-filling operations continued at RMA until late 1969. Between 1946 and 1982 parts of RMA were leased to private companies for manufacture of pesticide, insecticide, herbicide, and soil fumigant.

RMA lies within the High Plains physiographic province at an elevation of 5,140 to 5,340 ft above mean sea level. The topography is gently rolling with intermittent depressions. The overall slope is to the northwest toward the South Platte River. RMA lies within the South Platte drainage basin and contains parts of four defined tributaries: (1) First Creek, (2) Second Creek, (3) Sand Creek, and (4) Irondale Gulch. A fifth tributary area, referred to as the South Platte drainage, contains no defined main flow channel.

The average annual rainfall at RMA is about 14 in., but varies from less than 50 percent of average to over twice average during extreme years. Runoff is generally caused by snow melt and/or light rains in the spring, and by thunderstorms during the summer. Surface water entering the Arsenal is influenced by urban development. In addition, surface water is imported into the Irondale Gulch drainage of RMA via an irrigation canal, the Highline Lateral. Flows within the natural drainage basins on RMA have been greatly modified with man-made channels and impoundments.

The current surface-water monitoring program has evolved from a series of programs and studies originating in 1975. Called the 360 Degree Monitoring Program, it went through several revisions and involved several groups and agencies. During this pre-CMP period, several stream-flow gaging stations were installed.

The scope of work and procedures have changed as the flow system has become better understood, man-made modifications of the flow system have been implemented, and technical improvements in data gathering equipment and procedures have become available. Revisions of the 360 Degree Monitoring Program before CMP included analysis of continually expanding suites of analytes.

Pre-CMP Flow Data

This report includes a complete summary of pre-CMP flow data, consisting of mean daily flows and total monthly volumes, for WY82 through WY87. A review and evaluation of these data resulted in the following comments:

1. Continuous data are typically available only for April through November because of freezing weather during the winter.
2. Estimates of daily flows during the winter months were made in WY83, WY86, and WY89, but are not considered reliable except on days visual observations were made.
3. During April through November operation, there were several days when no gage-height record was obtained or estimated.
4. Strip chart recordings of continuous stage for WY84 and WY85 were never reduced. These data cannot be recovered accurately because of inadequate documentation of stage-discharge relationships, problems affecting strip chart recordings, or the relationship between strip chart stages and actual stream or rating stage.
5. Yearly trends cannot be accurately evaluated with available pre-CMP data because of the incomplete yearly records.
6. A detailed review and evaluation of pre-CMP stage and discharge records at one station (South Uvalda) using upgraded procedures including machine digitation, indicate significant errors may reside in the tabulated pre-CMP flow data, particularly peak flows, maximum daily mean flows, and total volumes of flow. The discrepancies are related to time increments involved in digitization and different ratings that were used.

Pre-CMP Surface-Water Quality Data

More that 2,000 water quality records of data collected between 1979 and 1987 were analyzed in the CMP effort. Sites of pre-CMP sampling were correlated with 17 current CMP surface-water sampling sites. The compounds detected at two or more CMP sites during the pre-CMP period were:

DBCP	11 sites
Chloroform (CHCL3)	8 sites
Dieldrin (DLDRN)	4 sites
Aldrin (ALDRN)	6 sites
DIMP	8 sites
Chlorophenyl methylsulfone (CPMSO2)	5 sites
Dicyclopentadiene (DCPD)	6 sites
Benzothiazole (BTZ)	3 sites
Chlorophenyl methylsulfoxide (CPMSO)	3 sites
Chlorophenyl methylsulfide (CPMS)	3 sites
Endrin (ENDRN)	3 sites
1,1,1-Trichloroethane (1,1,1-TCE)	2 sites

Isodrin (ISODRN)	2 sites
Toluene (MEC6H5)	2 sites
Hexachlorocyclopentadiene (CL6CP)	2 sites
Benzene	2 sites

An additional 16 compounds were detected at only one pre-CMP site each.

Five trace inorganic constituents were detected historically at current CMP surface-water sampling sites. Those detected at two or more sites were:

Arsenic (As)	11 sites
Zinc (Zn)	9 sites
Chromium (Cr)	3 sites
Lead (Pb)	2 sites
Copper (Cu)	2 sites

CMP Surface-Water Quantity Monitoring, FY88 and FY89

During FY89, surface-water quantity monitoring was conducted at 17 stations in the three main drainage basins defined on RMA. Two smaller drainage basins on RMA with minor surface-water flow were not monitored. Stream stage data are recorded continuously at 22 stations, and lake or pond levels were obtained weekly from five stations. New controls were constructed, and continuous recording equipment was installed along First Creek at South First Creek, North First Creek, and First Creek Off-Post locations.

Surface-water flow within the First Creek drainage basin is monitored at three locations. South First Creek monitoring station (SW08003) measures inflow from southeast off-post sources, North First Creek monitoring station (SW24002) measures streamflow leaving RMA, and First Creek Off-Post monitoring station (SW37001) measures flow between the northern RMA boundary and Highway 2.

Surface water was measured in the South Platte drainage basin at Basin A monitoring station (SW36001). This station is used to monitor runoff originating from the South Plants area.

New stream stage data acquisition systems were installed during FY89 at the South First Creek, North First Creek, South Uvalda, Havana Interceptor, and Peoria Interceptor monitoring stations. This equipment consists of digital data loggers and nitrogen bubbler systems. These systems permit collection of stage data during the freezing months, ease data reduction, and decrease the chance of human error. At all other stream monitoring stations, except Highline and South Plants ditch, datapod digital recorders were also installed to ease data reduction, and increase the accuracy and reliability of the flow data.

Surface-water quantity analyses included evaluation of stream-flow characteristics and extremes, as well as calculation of mean monthly, maximum daily and minimum daily flows. Stream-flow hydrographs were analyzed to describe flow conditions in response to six storms that occurred during FY89.

This report also contains information on groundwater and surface-water interaction in the South Plants Lakes area and along First Creek. This study involved the hydrographic and chemical analysis of surface-water locations and groundwater wells in these areas. The data indicate significant interaction in the South Plants Lakes area and along First Creek.

<u>CMP Surface-Water Quality Monitoring, FY88 and FY89</u>

During FY88, 29 surface-water quality locations were sampled and analyzed for 39 organic compounds. The most common organic compounds detected during FY88 are listed below in order of number of sites detected:

dieldrin (DLDRN)	5 sites
chloroform (CHCL3)	4 sites
aromatic volatile compounds (BTEX)	4 sites
hexachlorocyclopentadiene (CL6CP)	4 sites
dicyclopentadiene (DCPD)	3 sites

During FY88, the most frequently detected inorganics were:

zinc (total)	33 sites
mercury (total)	31 sites
lead (total)	31 sites
arsenic (total)	29 sites

During FY89, organic compounds were detected at 21 of 30 sites. The most common organic compounds were:

Vapona	7 sites
dimethylmethylphosphonate (DMMP)	6 sites
endrin	6 sites
dieldrin	5 sites
hexachlorocyclopentadiene (CL6CP)	5 sites
p,p'-DDE (PPDDT)	5 sites
aldrin, DIMP, chlordane, isodrin	4 sites

During FY89, the most commonly detected inorganics were:

zinc (total)	10 sites
arsenic (total)	10 sites
mercury (total)	4 sites

During FY88, quality analysis was performed on stream-bottom sediments from 10 locations. During FY89, sediment quality analysis was performed on samples from 18 locations. During FY89, organic compounds were detected at 16 sites. During the spring, the site with the most organic detections in sediments was SW36001 with nine organic compounds detected followed by SW01002, with six detections. The most commonly detected organics were:

atrazine	15 sites
dieldrin	6 sites
CMPSO	6 sites
endrin, isodrin, aldrin	5 sites

During FY89, seven high (storm) event samples were collected at surface-water sampling locations along the southern boundary and at interior locations that normally do not display surface water. Organic compounds were detected at three locations. Parathion, 2,4,5-trichlorophenol, and xylene (o,p) were detected at one station. DBCP was detected at the second station and dieldrin was detected at the third station. Zinc was detected in samples collected during storms at three stations and copper was detected at one station in samples collected during a storm.

Surface-water and groundwater interaction analysis has been addressed during the CMP along First Creek and in the area of the South Plants Lake. Based on a comparison of thalweg slope to groundwater elevations, various sections of First Creek are gaining or losing. This relationship is seasonally dependent and varies with groundwater levels and stream-flow characteristics. The analytical results for major ions and organic compound concentrations showed that alluvial groundwater and surface water north of RMA is similar.

In the South Plants area of hydrographic data indicates that Havana Pond, portions of Lower Derby Lake, the western portion of Ladora Lake and northwest portion of Lake Mary recharge to the groundwater. Hydrograph data in this area also indicate that the southeast portion of Lower Derby Lake, the eastern portion of Ladora Lake and southeastern portion of Lake Mary are being recharged by groundwater. Surface and groundwater had similar ion chemistry to lakes and nearby wells. However, the organic compounds detected in the lakes were not detected in the wells.

1.0 INTRODUCTION

The surface-water element of the Comprehensive Monitoring Program (CMP) at the Rocky Mountain Arsenal (RMA) has developed through the efforts of a number of programs and contractors over the years. The surface-water monitoring program has been periodically modified to expand or improve the collection of data. As the understanding of the dynamics of the hydrogeologic system at RMA has grown, improvements to the monitoring network have followed. Water monitoring has changed to reflect the changing goals for quantity and quality of surface water that emanates from RMA.

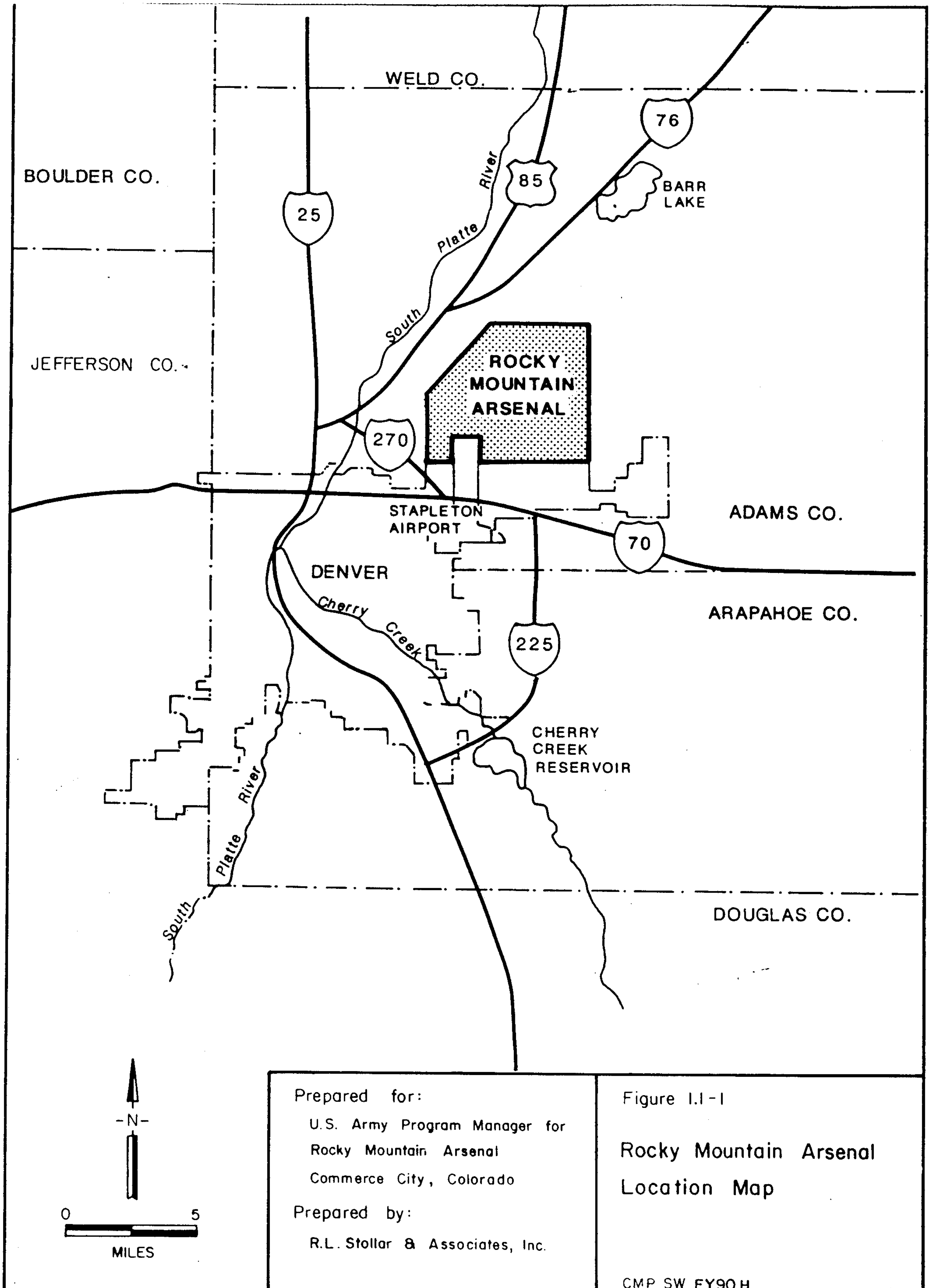
This report documents the chronology and development of the surface-water monitoring program at RMA between 1975 and 1987, including the first two years of the CMP (fiscal years 1988 and 1989). This document will complement the FY90 Surface-Water Data Assessment Report and future annual reports.

Section 1 of this report discusses the general setting of RMA in terms of geology, hydrology, physiography, and man-made features and how these elements affect in the surface-water system. This section also documents the evolution and development of the surface-water features on RMA. Section 2 reviews the previous surface-water programs and contractors involved with the two principal monitoring components of the CMP surface-water program. The programs concerned with the collection of surface-water quantity or quality data are discussed. Section 3 reviews and compares the scope of work and data collection procedures between pre-CMP programs and the surface-water element of the CMP. Section 4 presents and assesses historical surface-water quantity and quality data. The significance of trends or discrepancies noted in the surface-water data collected between 1975 and 1989 is evaluated.

The terms fiscal year (FY) and water year (WY) both correspond to the consecutive 12-month period beginning in October and ending in September. Both water year and fiscal year designations are used within this report.

1.1 SITE BACKGROUND

The RMA occupies approximately 27 mi^2 in southern Adams County, Colorado and is located about 6 mi northeast of downtown Denver (Figure 1.1-1). Before RMA was built in 1942, land in the area was used principally for dry farming, some irrigated farming and cattle grazing. At various times from 1942 to 1946, the U.S. Army produced chemical and incendiary weapons for use in World War II. Chemical agents were produced from 1953 to 1957. Munitions-filling operations continued at RMA until late 1969 (Ebasco Services, Inc. (Ebasco), et al., 1989a). From 1970 to 1982, Army operations at RMA centered on demilitarization of chemical weaponry. Between 1946 and 1982, parts of RMA were leased to private companies for chemical manufacturing. The two principal lessees, Julius Hyman and Company



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U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
R.L. Stollar & Associates, Inc.

Figure 1.1-1

Rocky Mountain Arsenal
Location Map

CMP SW FY90 H

and Shell Chemical Company, manufactured pesticides, insecticides, herbicides and soil fumigants (Ebasco Services, Inc., 1989c).

Land surrounding RMA is designated for varied uses. Mixed residential housing and light industrial manufacturing facilities are present along its western and southern borders. A part of Denver Stapleton International Airport's (Stapleton Airport) north-south runway system extends into the southwest portion of RMA. Land north and east of RMA is used mainly for farming and ranching. Principal features of RMA are shown on Figure 1.1-2.

1.2 GENERAL SETTING

RMA lies within the High Plains physiographic province. Topography at the Arsenal is characterized by gently rolling hills, with intermittent depressions occurring mostly in its west and northwest portion. Surface elevation ranges from approximately 5,340 ft above mean sea level (msl) in the southeast corner of RMA to 5,140 ft above msl along the southwest boundary. The overall topographic surface slopes to the northwest toward the South Platte River. First Creek is the only drainage that transects the entire Arsenal. The stream drops in elevation about 160 ft along its course through RMA.

The climate at RMA, with generally low humidity, light precipitation and abundant sunshine, is typical for the Rocky Mountain Front-Range Region. March and early April are the windiest and wettest months, with much of the precipitation in the form of snow. Historical climatological records (1958-1987) collected at Stapleton Airport (NOAA, 1987) indicate snowfall during these months ranges from 9.3 to 12.8 in., with 1.13 to 1.99 in. of precipitation in the form of rainfall. The most rain, an average of 2.41 in., falls in May. Summer precipitation falls principally from scattered thunderstorms during the afternoon and evening. Severe thunderstorms with large hail and heavy rain occasionally occur. Autumn is relatively dry with few thunderstorms and abundant sunshine. Historical mean average temperatures range from 30.1°F in January to 72.8°F in July. Large temperature variations in the winter result from invasions of cold arctic air from the north or warm Chinook winds from the west.

The two uppermost geologic units underlying RMA consist of Pleistocene to recent alluvial and eolian deposits and the Cretaceous to Tertiary Denver Formation. Unconsolidated Quaternary deposits are composed principally of fluvial sediments deposited by the ancestral South Platte River system, covered in part by wind-borne sediments. Eolian material varies in thickness to a maximum of 50 ft and consists of very fine to silty sand, sandy silt, and clay (MKE, 1988). Alluvial deposits consist predominantly of sands and gravels, which normally vary in thickness from 50 to 130 feet. Alluvium increases in thickness where deposition has occurred in paleochannels on the surface of the Denver Formation. Areas with less than 20 ft of alluvial and eolian deposits occur across RMA, mainly in areas overlying bedrock highs (Ebasco Services, Inc., et al., 1989a).

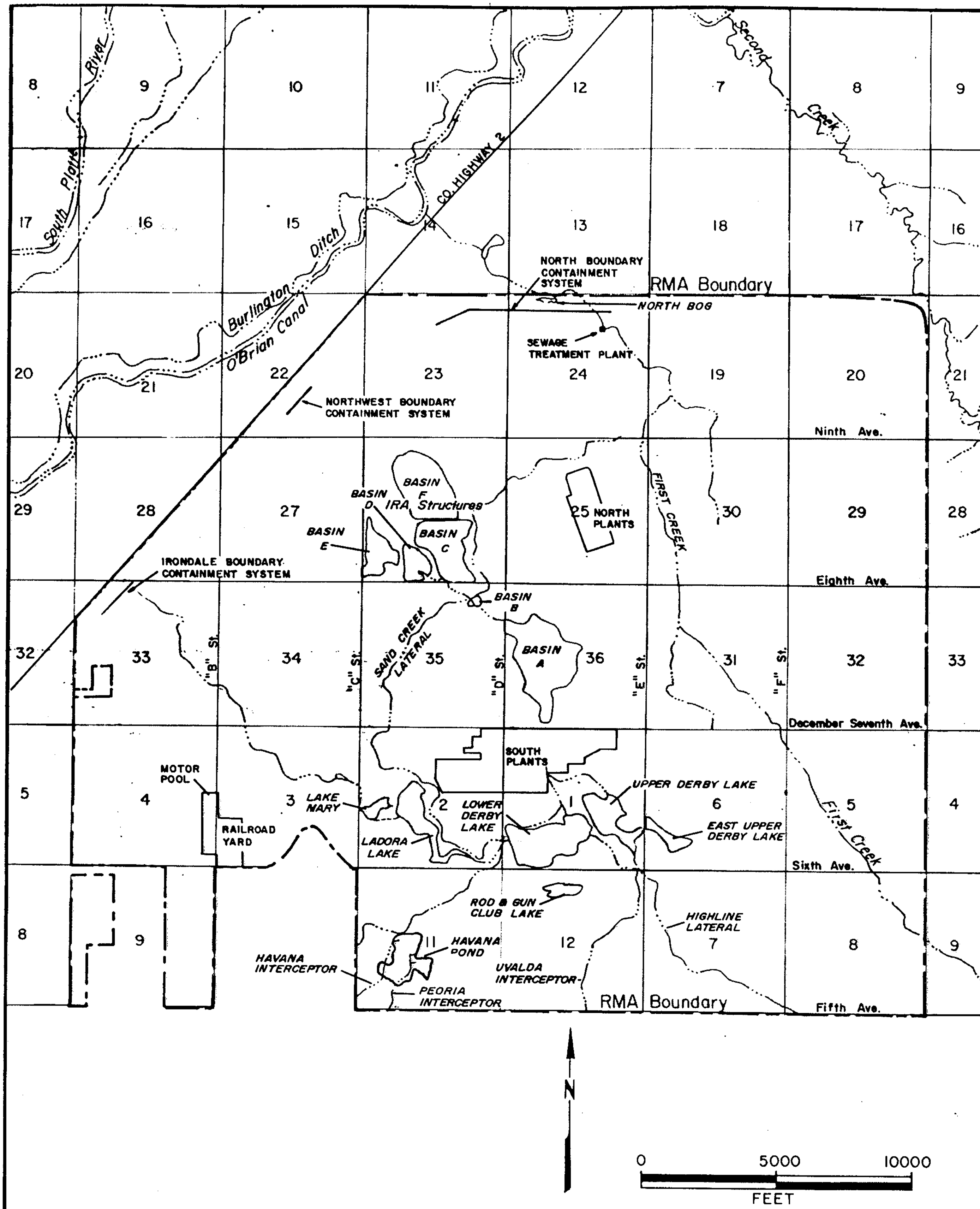

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Figure 1.1-2

Rocky Mountain Arsenal Features Map

CMP SW FY90H

The underlying Denver Formation is composed of interbedded bentonitic claystone, sandstone, siltstone, lignite and volcaniclastic deposits. Many of the beds are rich in plant remains and carbonaceous material. Sandstones are lenticular and laterally discontinuous. Individual sandstone intervals range in thickness from a few inches to 65 ft. Data suggest the total thickness of the Denver Formation underlying RMA is usually 200-500 ft (MKE, 1988). Denver Formation strata display a regional dip of about 1° to the southeast, resulting in relatively older stratigraphic zones subcropping against alluvium in the northwest portion of RMA, and progressively younger zones subcropping in the southeast. Quaternary sediments and the upper permeable portions of the Denver Formation are often in hydraulic communication at RMA and form the unconfined groundwater system (Ebasco, et al., 1989a).

1.3 GROUNDWATER HYDROLOGY

The groundwater system contributes significantly to the physical and chemical characteristics displayed by surface water at some RMA locations. An evaluation of the interaction between surface and ground water in certain areas across RMA is provided in Sections 4.7 and 4.8. The following is a brief overview of the general characteristics of the groundwater system at RMA.

Ground water at RMA occurs under both confined and unconfined conditions. Unconfined flow occurs in saturated portions of the eolian and alluvial Quaternary deposits and the uppermost permeable subcropping portion of the underlying Denver Formation. In areas where the Quaternary deposits are unsaturated, the unconfined flow system consists solely of sandstone and fractured or weathered rock within the upper portion of the Denver Formation. Saturated thickness varies from less than 10 ft to 70 ft (Ebasco, et al., 1989a). The regional unconfined flow direction at RMA is to the north and northwest. Deviations in these flow directions occur in the vicinity of the South Plants manufacturing facility and in the lakes area. A groundwater mound underlying South Plants creates divergent radial flow away from the area. Groundwater flow beneath Ladora Lake and Lake Mary is to the west, whereas flow directions beneath Upper and Lower Derby Lakes are less defined, but appear to have a predominant westward component (SSAR, 1989, Figure SSA 1.5-4, Ebasco, et al., 1989b).

Seasonal water-level fluctuations in the unconfined aquifer at RMA are generally less than 2 ft, although fluctuations as large as 6 ft have been measured beneath South Plants (Ebasco, et al., 1989a). Present-day recharge to the unconfined flow system occurs as infiltration of precipitation, seepage from lakes, streams, canals and buried pipelines, and discharging flow from the Denver Formation. Discharge from the unconfined flow system occurs primarily as seepage into Upper Derby Lake and possibly into portions of First Creek (Ebasco, et al., 1989a). Man-induced fluctuations in the water table surface have resulted from withdrawal of water in water supply wells, activities which affect the mass balance of the lakes, and operations at the ICS and Northern IRA areas (RLSA, 1990c). West of the Irondale Treatment System, localized water table fluctuations of approximately 15 ft have occurred due to the pumping of a water supply well for Adams County.

1.4 Surface-Water Features

Surface water at RMA can be discussed in terms of both larger and smaller features. Five drainage basins encompass RMA. Natural and man-made lakes, ditches and creeks exist within these basins. The general characteristics of the drainage basins on RMA are discussed in Section 1.4.1. Surface-water features within the principal drainage basins are discussed in Section 1.4.2.

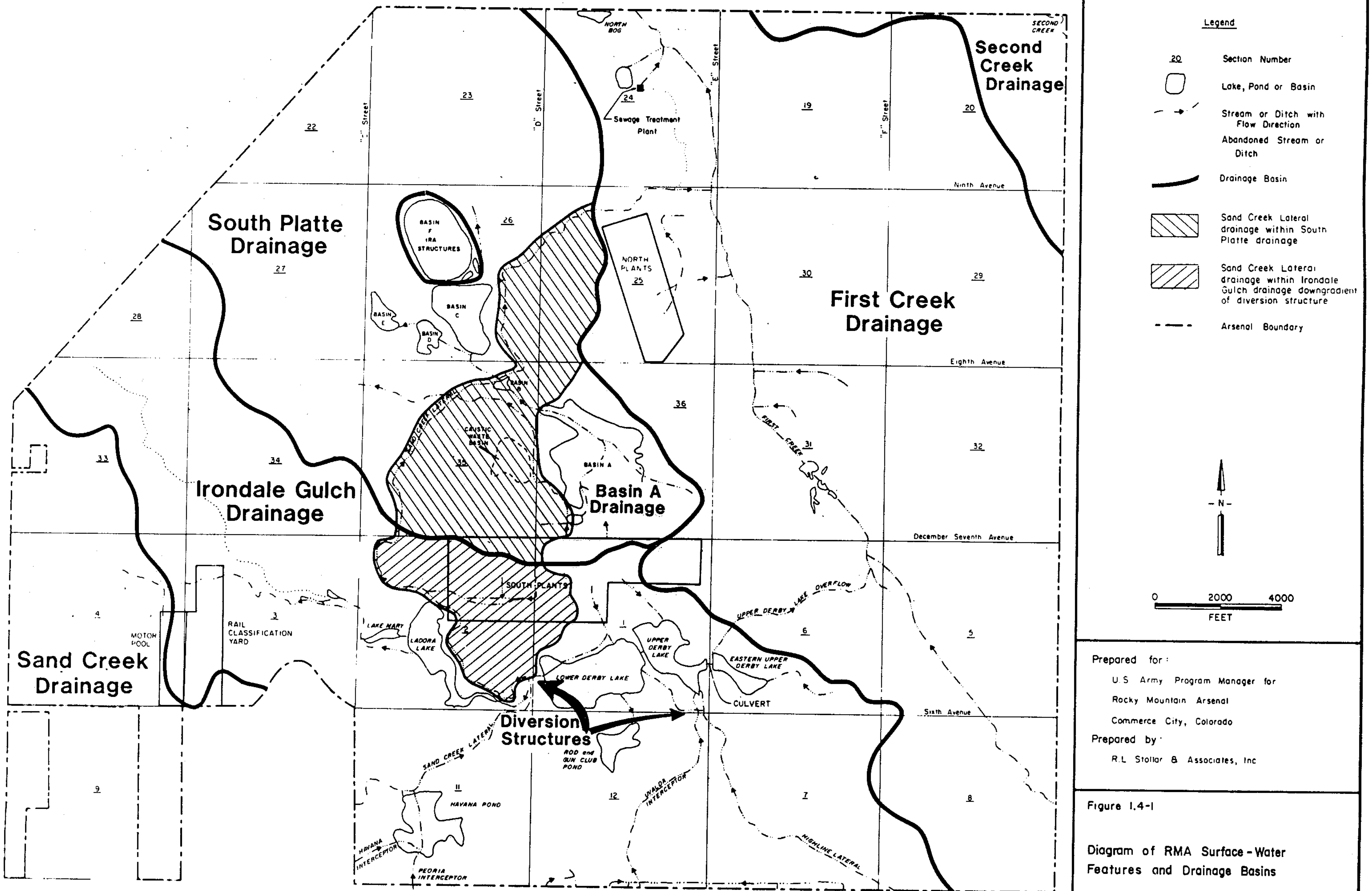
1.4.1 Drainage Basins

RMA lies within the South Platte River drainage basin. Surface-water on RMA flows within several smaller drainage basins that are tributaries to the South Platte River. First Creek, Second Creek, Sand Creek, and Irondale Gulch drainage basins (Figure 1.4-1) contain defined channels that flow mainly to the north and northwest. The northwestern portion of RMA has no subdrainages to the South Platte drainage basin, and there are no well-defined channels. The drainage basins on RMA are discussed below. Subcatchments of the South Platte drainage basin (Basin F and Basin A drainages) are discussed in Section 1.4.2.3.

1.4.1.1 First Creek Drainage Basin

The First Creek drainage basin originates in Arapahoe County, Colorado, about 20 mi east of downtown Denver. The basin is about 26 mi long and varies in width from 1 to 4 mi (Figure 1.4-2). First Creek drains about 27 mi^2 upstream of RMA and approximately 12 mi^2 on RMA. Land use upstream of the Arsenal is primarily agricultural (U.S. Army Corps of Engineers, USACE 1983a). Soil infiltration capacities in the southeast portions of the First Creek Basin are low (0.06 - 2 in./hr) to moderate (0.6 - 6 in./hr), increase at the southeastern boundary of RMA, and are moderate within RMA boundaries (RCI, 1982). Off-post soil infiltration capacities upgradient of RMA are expected to change with the continued development associated with the new Denver Airport and Green Valley Ranch. The topography of the First Creek Basin within RMA is gently undulating with low hills.

First Creek flows about 26 mi northwesterly from its source to its confluence with O'Brian Canal about 0.5 mi north of the northern boundary of RMA. This includes about 5.5 mi of channel on RMA. In dry years, the flow of First Creek on the Arsenal is usually continuous only during the spring and after major storms, but the creek is regulated to some extent by the Highline Lateral spillover, upstream from RMA. During wet years, the general persistence of flow along the creek is evidenced by well-developed hydrophytic and phreatophytic vegetation along most of its length. There are eight road or railroad crossings over First Creek within RMA. The original crossings consisted primarily of culverts with



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U.S. Army Program Manager for

Rocky Mountain Arsenal

Commerce City, Colorado

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Figure 1.4-1

Diagram of RMA Surface-Water Features and Drainage Basins

CMP SW FY90H

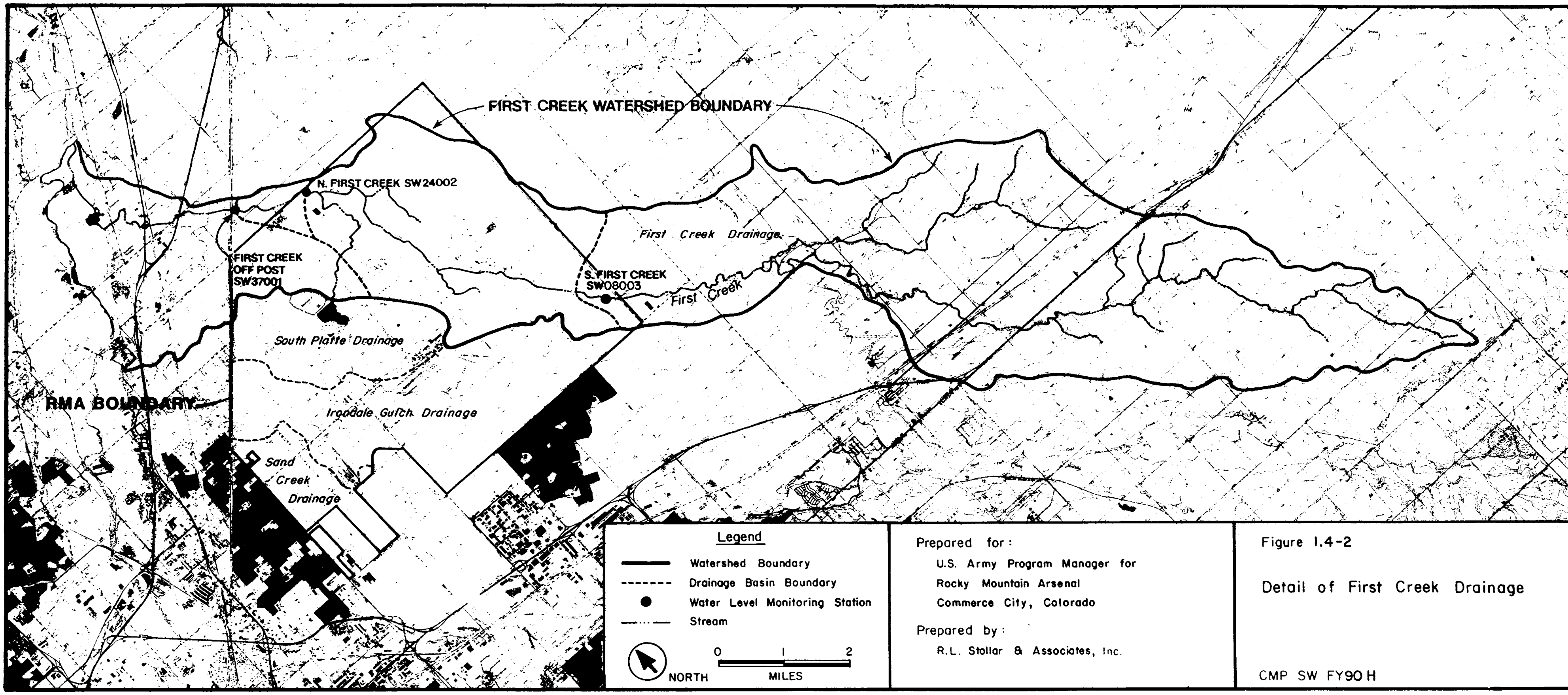

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Figure 1.4-2

Detail of First Creek Drainage

CMP SW FY90 H

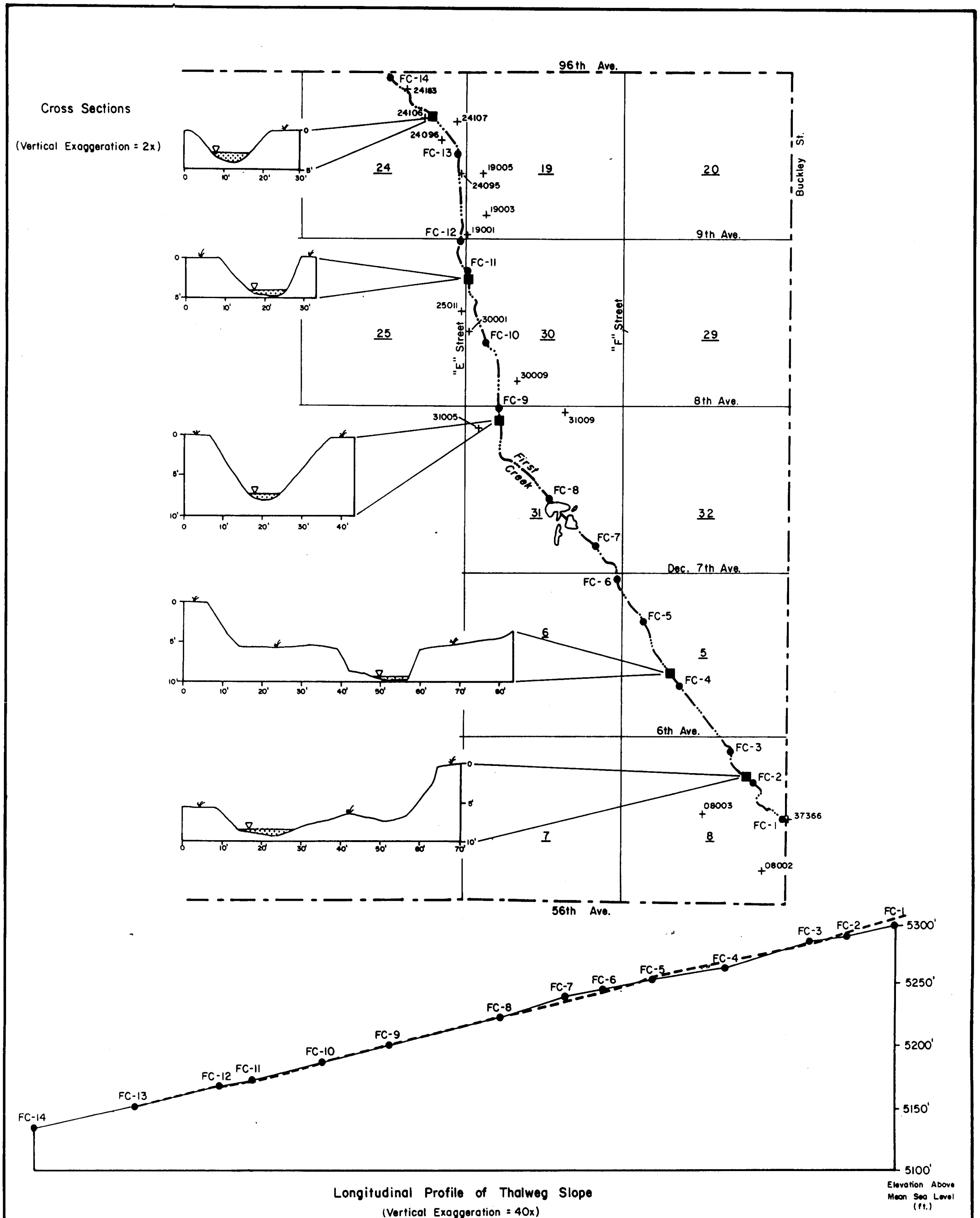
limited flow capacities beneath the roadways (USACE, 1983a). Four roadway culvert systems with enlarged capacities have been built on First Creek since 1988 at crossings under F Street, December Seventh Avenue, Sixth Avenue and the north Boundary Containment System access road in Section 24. In late April 1989, 14 locations along First Creek on RMA were surveyed to determine thalweg slope and surface-water elevations. Surface-water elevations were compared to groundwater elevations in nearby monitoring wells. An attempt was made to identify areas of influent or effluent conditions along First Creek. Further discussion of groundwater interaction with First Creek is provided in Section 4.4. Thalweg elevations and five cross sections measured at selected points on the creek are shown in Figure 1.4-3.

Along the southern reach of First Creek, between survey points FC-1 and FC-8, the average thalweg slope is 29.87 ft/mi. Along First Creek's northern reach between survey points FC-9 and FC-13, the slope decreases to 29.20 ft/mi. This difference in slope is accompanied by a difference in channel geometry between the southern and northern reaches (Figure 1.4-3). Along the southern reach (in Sections 5 and 8) the creek is wide and in places has terraced banks. Upper bank-to-bank widths are up to 90 ft along some terraced sections. Bank widths of the main channel are generally about 20 feet. Along outside channel bends, banks are steep and occasionally undercut. Banks are composed of poorly consolidated silty sand. Sloughed bank material is deposited along some outer channel bends. Grassy vegetation stabilizes the more gently sloping channel banks. Maximum bank height is up to 10 feet. Intermittent intrachannel bars and point bars indicate channel adjustment and sediment transport in this portion of First Creek.

An extensive marshy area exists along First Creek between December Seventh Avenue and survey point FC-8. The marsh is several hundred feet wide in places, and is caused by breaches in three man-made earthen dams just south of survey point FC-8. Ponded water stands in the earthen dam embankments (Figure 1.4-3).

Along the northern reach of First Creek on RMA, the channel has a smooth concave-upward shape and banks are generally less steep. Bank top widths range from 35 to 55 ft. Bank height ranges from 4 to 8 ft, generally decreasing toward the north end of this stretch. Bank material is generally silty sand stabilized by grassy vegetation.

Most of the course of First Creek on RMA is straight. Channel meandering is most common in Section 8 where First Creek comes on post. The channel was straightened in the northwest portion of Section 5 and on the east side of Section 24 following a major flood in 1973 (USACE, 1983a). The capacity of the creek is about 250 cfs as it enters RMA and about 300 cfs downstream of the sewage treatment plant outfall at the north boundary (RCI, 1982). Average monthly flows recorded during WY89 from April to September at the new South First Creek gaging station (SW08003) ranged from 1.5 cfs in May to 0.11 cfs in September. Average monthly flows during WY89 for April to September recorded at the new



Legend

7	Section Number
	RMA Boundary
	Stream or Ditch
	Area of Ponded Water
FC-8	Survey Elevation Location
	Cross Section Location
	Water Table Elevation (April, 1989)
08002	Monitoring Well Location
	Cross-Sectional Morphology of First Creek Stream Flow
▽	Water Surface

ROCKY MOUNTAIN ARSENAL LOCATION

-N-

0 3000 6000

FEET

Prepared for:
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
R.L. Stollar & Associates, Inc.

Figure 1.4-3

Thalweg Slope and Cross Sections of First Creek

CMP SW FY90 H

north First Creek gaging station (SW24002) ranged from 1.2 cfs in May and June to 0.00 cfs in July, August, and September.

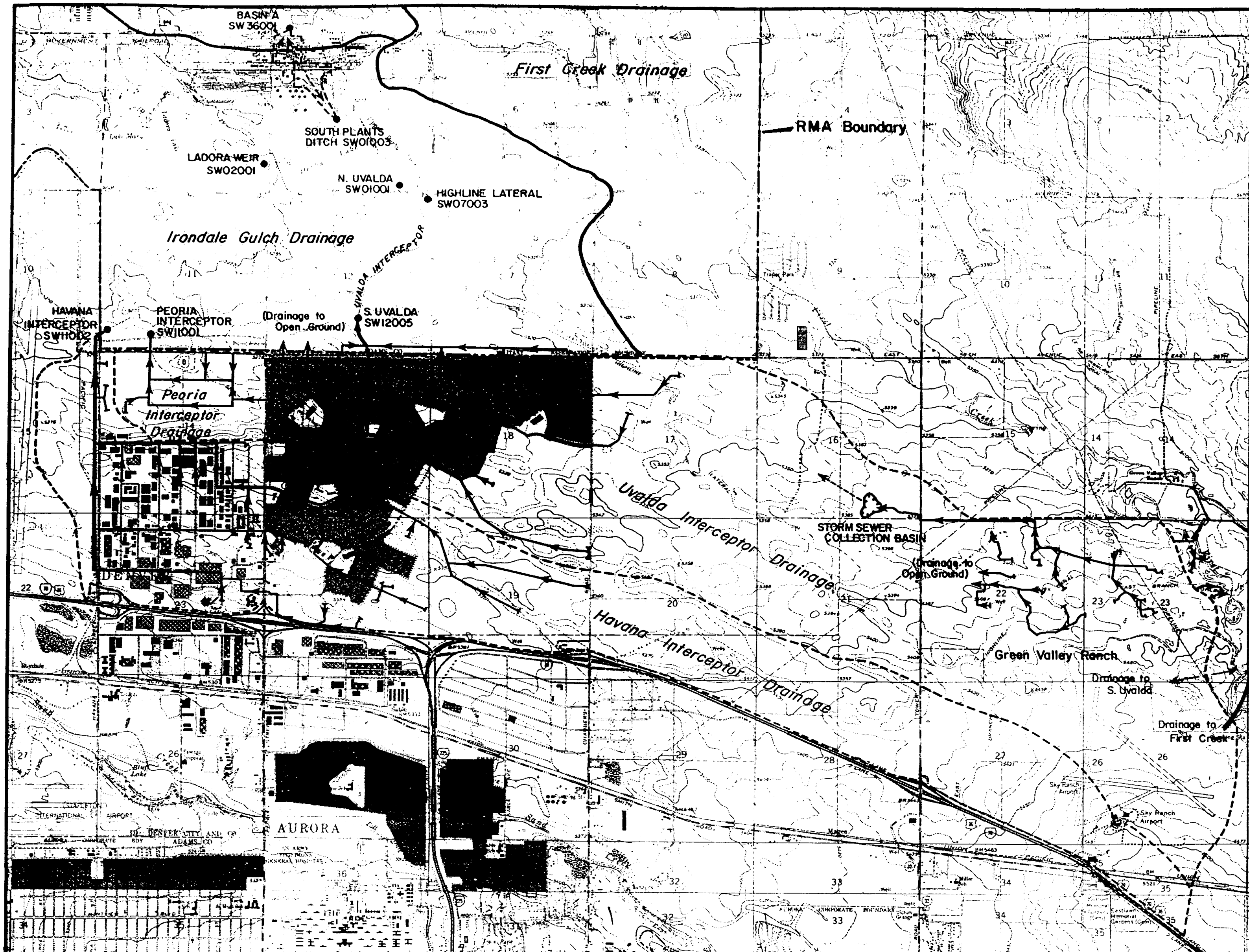
Storm sewer drainage is currently being routed into First Creek from the northeast portion of the Green Valley Ranch residential area. The storm runoff is collected in the vicinity of Nepal Street and 48th Avenue from an area of 0.177 mi^2 (Figures 1.4-2, 1.4-4).

Highline Lateral canal sometimes adds flow to First Creek. Highline Lateral crosses First Creek on the eastern side of Green Valley Ranch. An overflow diversion channel for the Highline Lateral is located at this intersection. The channel directs overflow from the Highline Lateral canal into First Creek, as occurred during WY89 and WY90.

As First Creek traverses RMA, several drainages can contribute to its flow (Figure 1.4-1). The first well-defined drainage, an old overflow ditch from eastern Upper Derby Lake, enters First Creek in Section 6. Under normal flow conditions, this ditch no longer carries water from Upper Derby Lake. First Creek then flows through three breached small detention or retention dams in Section 31. When intact, the combined available storage behind these dams was about 150 ac-ft (USACE, 1983a). The next drainage ditch joins First Creek in the northwest corner of Section 31. It drains the old Toxic Storage Yard. The North Plants area is drained by a ditch that joins First Creek in the central-western portion of Section 30. The Sand Creek Lateral enters First Creek near the northeast corner of Section 25; the infrequent flows in the lateral rarely reached the confluence in the past several years, though this did occur in WY89.

Effluent from the Sewage Treatment Plant is directed toward First Creek via a ditch in the northeast portion of Section 24. Just before First Creek crosses the north boundary, it intercepts a small channel which drains overflow from the North Bog. North Bog is a 2.7-acre (117,000 ft^2) body of water located in the northwest quarter of Section 24. During high flow, water from First Creek flows into the bog. Since 1983 the North Bog has been used as a natural recharge receptacle for treated ground water from the north Boundary Containment System (Ebasco, 1988a).

In the fall of 1988, First Creek was diverted away from a stand of trees near the south-central border of Section 5. A new culvert was placed under Sixth Avenue approximately 300 ft west of its old location. The creek was diverted in this area to reduce bank erosion and associated deterioration of the trees along this section of the creek. The trees along First Creek have become the seasonal roosting location of many eagles. This construction also produced a small retention pond just south of Sixth Avenue on First Creek. This pond is designed as a habitat for eagles and waterfowl. The effect of surface-water ponding at this location on local groundwater conditions has not been determined at this time. There is a potential for creating an area of increased groundwater recharge by restructuring the flow of water along this section of First Creek.



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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
R.L. Stollar & Associates, Inc.

Figure I.4-4

Detail of South Boundary Storm Sewer Drainages

CMP SW FY90H

1.4.1.2 South Platte Drainage Basin

About 6 mi^2 in the northwest corner of RMA drain toward the South Platte River. This subcatchment is bounded by the Irondale Gulch drainage to the southwest, the Sand Creek Lateral to the east and southeast, and First Creek to the northeast (Figure 1.4-1). The South Platte drainage does not contain a distinct channel and is characterized by a large number of natural depressions similar to Sand Creek Basin. Three subordinate drainages — Basin A, Basin F, and the Sand Creek Lateral Sub-Drainage — have been delineated within the South Platte Drainage Basin. Characteristics of these smaller sub-drainages are discussed in Sections 1.4.2.1 (Diversion Channels and Ditches) and 1.4.2.3 (Collection Basins). Soil infiltration capacities (2 - 20 in./hr) are high in the central and southwest portion of the subcatchment; moderate (0.6 - 6 in./hr) in the west, southeast and north-central areas; and low (0.06 - 2 in./hr) in the north-northeast sections where bedrock is near the surface (RCI, 1982). Due to the low infiltration rates, more overland flow is expected in the north-northeast area of this subcatchment. The flow would be toward the north and west boundaries of RMA.

1.4.1.3 Irondale Gulch Drainage Basin

The southern boundary of the Irondale Gulch Drainage Basin is at the intersection of Interstate 70 and East Colfax Avenue. The area of drainage consists of 11.5 mi^2 upstream of RMA and 6.5 mi^2 of RMA. Surface-water flow is to the northwest. The drainage area consists of low rolling hills. Vegetation is mainly grasses, with some scattered trees along the lakes and channels and in some low areas (USACE, 1983d).

The Irondale Gulch Basin on RMA includes four lakes and several other impoundments. The Havana and Peoria Interceptors, Uvalda Street Interceptor and Highline Lateral all flow from south of RMA to the lakes (Figure 1.4-1). Upstream drainage patterns have been modified by the construction of subdivisions, channelizations and storm drains. Upstream land use consists of light industrial, urban residential, open range land, and a portion of Stapleton Airport. Urban development covered 32 percent of the basin in 1983 and was expected to increase (USACE, 1983a).

Soil infiltration rates are high throughout most of the Irondale Gulch Drainage Basin, except southeast of the lakes on RMA where rates are reported to be moderate (RCI, 1982). Natural drainage channelization is poorly defined or lacking over most of Irondale Gulch Basin on RMA, due in part to the moderate-to-high soil infiltration rates.

Superimposed on these natural drainage basins are man-made structures that have modified the surface-water system. These structures include diversion ditches, major lakes, impoundments developed to retain storm runoff, as well as many culverts, storm and sanitary sewers, and other control structures.

1.4.1.4 Sand Creek Drainage Basin

Sand Creek drainage includes 2.2 mi^2 in the southwest area of RMA. The lack of any major channelized flow has been attributed to the high infiltration capacities (2 - 20 in./hr) of the soils in this area (RCI, 1982). Many natural depressions in the basin intercept runoff, so that surface flow tends to be local. If extreme precipitation occurs, runoff could progress from one depression to another in a northwesterly direction, finally exiting at RMA's western boundary (RCI, 1982, Plate II).

The Sand Creek drainage is interrupted by the Stapleton Airport runways and drainage system, which extend into Section 10 adjacent to RMA. Some runoff from the airport and the Sand Creek drainage is intercepted by the Havana Interceptor, which returns the flows to RMA within the Irondale Gulch Drainage Basin (Figure 1.4-1). A detailed hydrologic analysis of the drainage in this area was performed as part of the Stapleton Airport expansion studies (Wright-McLaughlin Engineers, 1969).

Land used upstream from RMA in Sand Creek Basin is dominated by Stapleton Airport and related facilities. Prior to construction of the north-south runway, Sections 9 and 10 and were used as buffer zones for Arsenal operations. A U.S. Post Office installation is located in Section 9.

1.4.1.5 Second Creek Drainage Basin

Only a small portion of Second Creek Basin is present in the northeast corner of RMA (Figure 1.4-1). The basin has a total drainage area of 20.6 mi^2, of which only 0.6 mi^2 are within RMA. Upstream of RMA, Second Creek Basin is 9.1 mi in length. The width of the basin varies from 1 to nearly 3.5 mi, and the main channel length is 12.3 miles. The main stream channel crosses the northeast corner of RMA, traversing less than 1,000 ft of the Arsenal. Drainage is to the northwest (RCI, 1982). The soils of the Second Creek Basin have low infiltration capacities upstream of RMA, where land is used primarily for agriculture. Soils along Second Creek drainage on RMA have low to moderate infiltration capacities. The more incised and sinuous nature of the channels in this drainage, in comparison with that of First Creek, may be attributed to the lower infiltration rates exhibited by the soils in the Second Creek drainage (RCI, 1982). The portion of Section 20 that lies within Second Creek drainage has been used as a buffer zone for Arsenal operations.

1.4.2 OTHER SURFACE-WATER FEATURES

The following sections discuss characteristics and development history of the principal surface-water features that direct or constrict flow within the major drainage basins on RMA.

1.4.2.1 Diversion Channels and Ditches

Flows within the natural drainage basins on RMA have been greatly modified through the construction of a number of diversions (laterals) and drainage channels (interceptors). The principal channels on RMA — Highline Lateral, Uvalda Interceptor, Peoria Interceptor, and Havana Interceptor — enter along its southern border and carry water to the lakes near South Plants or Havana Pond.

Highline Lateral (canal) enters RMA near the southwest corner of Section 8 and flows northwest to a diversion box in the southeast corner of Section 1. At this structure, flow can be directed either north to Upper Derby Lake or merged with the Uvalda Interceptor and emptied into Lower Derby Lake (Figure 1.4-1). Since 1942, the Highline Lateral has been used as an intake canal for water delivery to the South Plants Lakes from the South Platte River. The canal is operated by the Denver Water Department, with deliveries based on seasonal availability and shares owned by RMA. Approximately 1.7 mi of Highline Lateral lie on RMA. The lateral has an average bottom width of 8 ft and an average channel depth of 4 ft. Discharge capacity is calculated to be 75 cfs (USACE, 1983a). During WY89, when the canal was in use, maximum average daily discharges ranged from 22.0 cfs in May to 7.2 cfs in August.

Uvalda Interceptor enters RMA near the center of the southern border of Section 12 and flows north about 1.2 mi to a diversion structure in the southeast corner of Section 1. From this point, flow can be directed to Upper Derby Lake or Lower Derby Lake, and may be merged with flow from Highline Lateral. Uvalda Interceptor was completed in 1967 to channel runoff from the Montbello subdivision, adjacent commercial industrial areas, and rangeland south of RMA. The drainage basin area for the Uvalda Interceptor is about 7.8 mi^2, of which 4.12 mi^2 is residential, with an associated storm sewer system. Normally, the Uvalda Interceptor receives storm runoff from the northern portion of Montbello and the undeveloped area directly west of Chambers Road. Storm runoff from the Green Valley Ranch residential area drains into Irondale Gulch drainage via Uvalda Interceptor during significant rainfall. The storm sewer discharge area for Green Valley Ranch is a collection basin located west of the development. Overflow from this basin could enter the Montbello storm sewer system, and eventually the Uvalda Interceptor (Figure 1.4-4). This channel has a discharge capacity of 1,200 cfs at the south RMA boundary and 600 cfs near Sixth Avenue (USACE, 1983a). The average channel bottom width is 7 ft, and the average channel depth is 8 ft (Larsh, 1969).

The Havana Interceptor drainage basin encompasses industrial and residential areas south of RMA. Surface-water flow is directed toward the north-northeast across Section 11, and terminates in the Havana Pond. Havana Interceptor drains land with commercial and light industrial development, residential housing and some rangeland (RCI, 1982). A portion of the storm runoff from Stapleton Airport is also included in the drainage received by the Havana Interceptor (ESE, 1985). Havana Interceptor is a concrete-lined canal as it enters RMA. The drainage basin for the Havana Interceptor is about 5.22 mi^2, of which 2.6 mi^2 is storm sewer drainage. This drainage receives runoff from the southern portion of

Montbello and the industrial complex on the south side of RMA. The drainage subbasin extends in a narrow zone east to about Sky Ranch Airport and is bounded on the south by Interstate 70 (Figure 1.4-4).

Peoria Interceptor enters RMA along the southern edge of Section 11 and flows about 0.3 mi before joining Havana Interceptor and emptying into Havana Pond. The Peoria Interceptor drains the northern portion of the industrial complex located on the south side of the Arsenal. Storm sewer runoff from a small portion of western Montbello is also directed toward the Peoria Interceptor. The .644-mi^2 drainage basin is almost entirely urban storm sewer runoff (Figure 1.4-4). Construction of the interceptor was completed in 1980 (Stout and Abbott, 1982). Havana Pond contains 5 ac-ft of water covering 5 ac during normal pool storage. In the past, water levels were kept low to allow for additional storage capacity during floods. The pond originally could hold 79 ac-ft of water covering 22 ac if filled to the crest of the embankment (USACE, 1983d). Two separate mechanisms are in place to discharge water from Havana Pond to Sand Creek Lateral. A valve-controlled sluice gate on an 18-in. pipe is used to manually regulate flow out of the pond. In the fall of 1988, a 56-ft long, 12-ft wide concrete spillway was installed to allow overflow during a 10-year or greater flood event. At overflow the pond holds 30 ac-ft of water.

Sand Creek Lateral enters RMA along the western edge of Section 11 just north of Havana Pond. A short ditch connects the spillway and a valve-controlled discharge point at the north end of the pond to Sand Creek Lateral. This lateral originally was connected to Sand Creek, which flows about 1.2 mi southwest of the Arsenal, and was used to carry irrigation water to farms on land now occupied by RMA (MKE, 1987). Construction of the northern extension of Stapleton Airport filled in a portion of the lateral and disconnected it from Sand Creek. The lateral leaves Irondale Gulch drainage in the southern portion of Section 35, flows northeast through the South Platte drainage, and terminates at First Creek in the First Creek drainage. The Sand Creek Lateral intercepts surface flow within the Irondale Gulch and South Platte drainages and is therefore considered to have a catchment area (Figure 1.4-1).

During the CMP years, water was normally released from Havana Pond to Sand Creek Lateral only after large storms, but recent efforts have been made to keep the stage at Havana Pond below 2 ft. The sluice gate used to regulate flow out of the pond to the lateral was opened when the water level on the staff gage measured 6 feet. The gate was closed when the staff reading declined to 4 ft (James Green, Chief Facility Engineer RMA, personal communication, 1989). A staff gage reading of 6 ft corresponds to 121.81 ac-ft of water being held in the pond, while 4 ft on the staff gage means that 59.84 ac-ft of water is present in Havana Pond (Ebasco Services, Inc., et al., 1989a). Flow in Sand Creek Lateral could also originate from the South Plants lakes (Upper Derby Lake via Lower Derby Lake) if water were released into the lateral from Lower Derby Lake at the Ladora Weir rather than being diverted into Ladora Lake. Surface drainage and runoff from the southwestern area of South Plants is intercepted by Sand Creek Lateral downgradient of the diversion structure. Water pumped from three wells located in Section 4, which is used to supplement water in the South Plants lakes, can also be discharged into Sand Creek Lateral.

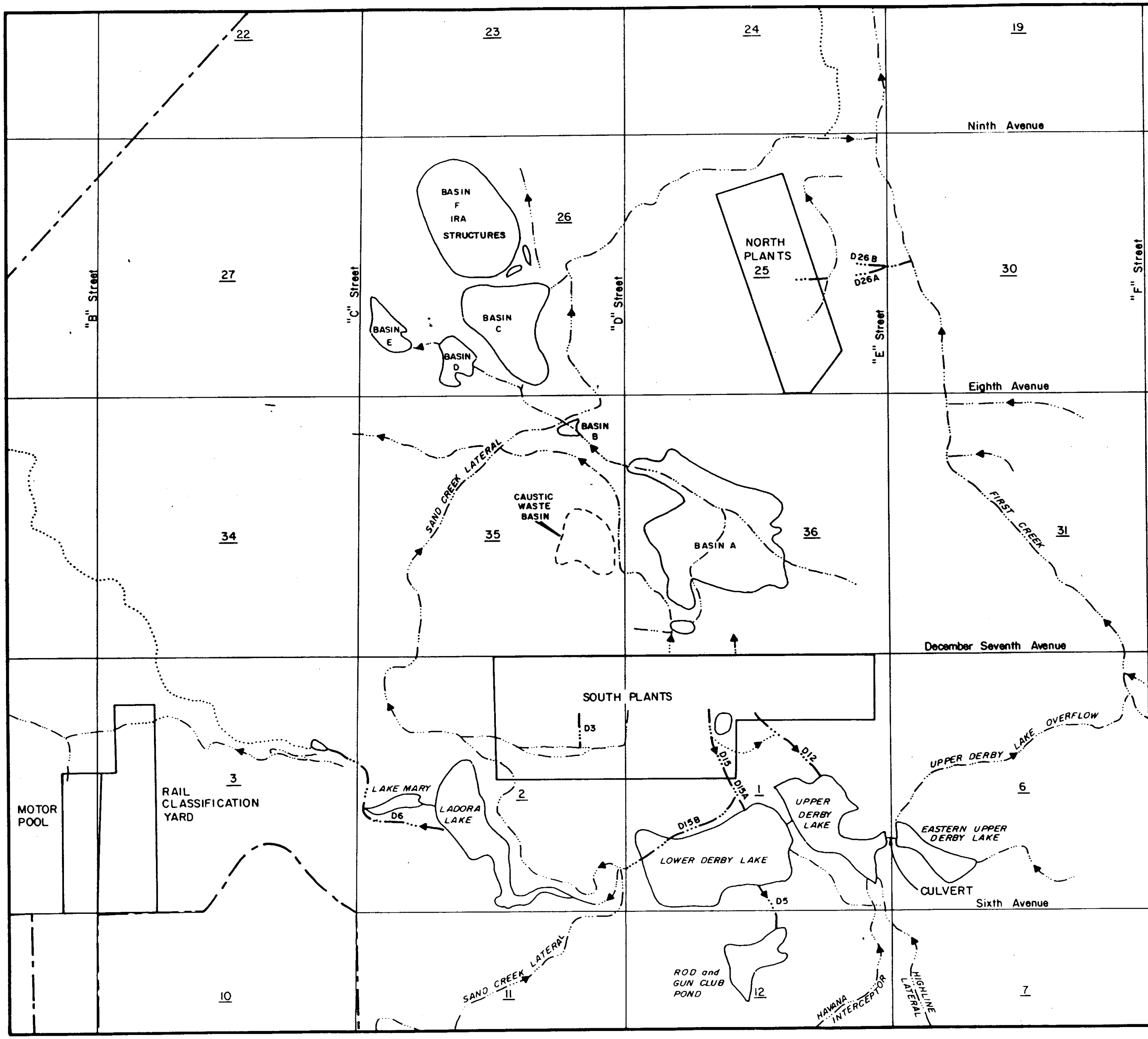
Within the South Platte drainage, a channel is located near the eastern boundary of the catchment. The channel originates near the Lime Settling Ponds in Section 36. Water within this channel flows under Sand Creek Lateral and into the South Platte drainage.

The Sand Creek Lateral catchment within the South Platte drainage also contains a reservoir in the eastern side of Section 35 which usually is dry. The reservoir was designed and constructed, but never used, as a basin to receive caustic waste from the South Plants area. The caustic waste basin does not have a formal outlet, making it probable that no surface-water flows escape the caustic waste basin, and that all precipitation is stored, evaporated, transpired or infiltrated. Flow in the Sand Creek Lateral can be diverted to Basin C, and was so diverted from 1953 to 1956. Aqueous waste overflows from Basin B were also diverted to Sand Creek Lateral during that period.

1.4.2.2 Lakes and Ponds

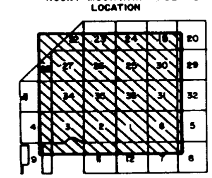
Four lakes and two ponds lie within the Irondale Gulch Drainage Basin at RMA (Figure 1.4-1). These bodies of water are significant in the groundwater/surface-water interaction at the Arsenal. Further discussion of the hydraulic communication among these surface-water bodies and the groundwater flow system at RMA is provided in Sections 4.7 and 4.8. Three of the larger impoundments (Upper Derby Lake, Lower Derby Lake and Ladora Lake) were used as part of the process water system from 1942 until 1964. These lakes are connected to several diversion channels used to supply or divert water from the lakes. The lakes were used to dissipate heat from water used in manufacturing in South Plants and to store water for fire protection. Water was pumped from the northwestern (lower) end of Ladora Lake, circulated through various South Plants manufacturing facilities, and then discharged into Upper Derby Lake via an open return water ditch (D12) located at the north end of the lake (Figure 1.4-5). The lakes formed a natural cascading flow system, with water being cooled as it moved from Upper to Lower Derby and finally into Ladora Lake.

In 1963, the return-water ditch was rerouted to bypass Upper Derby Lake and drain directly into Lower Derby Lake (MKE, 1987). In 1964, the portion of the lakes system serving the eastern section of South Plants was converted to a closed-loop system using a cooling tower (Ebasco Services, Inc., 1988c). The South Plants lakes were not used to cool the manufacturing process after 1964, but continued to serve as a cooling system for the Arsenal's steam plant and to replace water lost from the closed-loop system (MKE, 1987).



Legend

26	Section Number
	RMA Boundary
	Stream or Ditch
D6	Return Water Ditch with Identification Number
	Abandoned Ditch
	Lake, Pond or Basin



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U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by :

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Figure 1.4-5

Location Map of Return Water Ditches

CMP SW FY90H

The eastern portion of the process water loop using the cooling tower and associated sedimentation pond has not operated since 1976. An elevated storage tower is kept full of on-demand water (Stearns-Rogers Engineering, personal communication, 1989). Currently, process water used for the steam plant and irrigation is taken from a pump station near the north end of Ladora Lake. Return water from the steam plant is discharged into a north-south oriented ditch located south of the facility (D-3, Figure 1.4-5). This ditch in turn connects to a series of ditches leading to Sand Creek Lateral.

The process water system is also discussed in Section 1.5. The remainder of this section discusses the history and physical characteristics of the individual lakes and ponds.

1.4.2.2.1 Upper Derby Lake

Upper Derby Lake is the uppermost lake that was used in the process water cooling system. The main part of the lake is located in the southwest quarter of Section 1. The eastern extension of the lake (Eastern Upper Derby Lake) is located across E Street (Figure 1.4-1). Upper Derby Lake was created by constructing a dam east of Lower Derby Lake to increase the volume of water in storage for the process water system. Upper Derby Lake was built shortly after Lower Derby Lake and originally was lined with clay to reduce seepage. Between 1964 and 1965 the lake bottom was excavated to remove contaminated sediments. Between 1980 and 1982, the lake was drained and natural revegetation occurred. Since that time it has been used for flood control (Knaus, 1982). Upper Derby Lake can receive inflow from Highline Lateral and the Uvalda Interceptor. The surface area of the lake at full capacity is 83 acres, with a storage capacity of 460 ac-ft (Graff & Reilly, 1943).

Eastern Upper Derby Lake has a clay-lined bottom and covers about 15 acres. The Upper Derby Lake overflow ditch exits from the north edge of the lake and flows northeast toward First Creek. In the spring and early summer months, the lake can be filled by surface-water inflow through a culvert from Upper Derby Lake. Typically, during the late summer, fall and winter months when surface-water runoff is low, the lake is marshy or dry (Ebasco Services, Inc., 1987b).

1.4.2.2.2 Lower Derby Lake

Lower Derby Lake is in south-central Section 1 between Upper Derby Lake and Ladora Lake (Figure 1.4-1). It is visible on a July 16, 1937 air photograph, but was smaller. The lake was used as an irrigation reservoir when RMA was established. In 1942, the lake's storage capacity was increased when the Army modified the existing earthen dam by raising the crest 3 ft, regrading the sides, and installing a new drain line (U.S. Army Chemical Warfare Service, 1945). The lake was originally lined with clay to reduce water seepage (Gatlin, 1964, in Ebasco, 1987c). In 1963, use of the easternmost return ditches (D12, Figure 1.4-5) ceased. Instead of flowing to Upper Derby Lake, drainage from the South Plants area was rerouted to Lower Derby Lake through ditches D15 and D15A (Figure 1.4-5)

(Williams, 1963, in Ebasco, 1987c). In 1964, installation of a closed-loop cooling tower system effectively removed the lakes from the process water system (Culley, 1971, in Ebasco, 1987c), and a ditch (D15B, Figure 1.4-5) was constructed at the northwest end of Lower Derby Lake to connect with a pipe and drain into Ladora Lake (Donnelly, 1983, in Ebasco, 1987c). This diversion controlled outflow from Lower Derby Lake. Between 1964 and 1965, contaminated sediment was excavated from Lower Derby Lake (Kenny, 1965, in Ebasco, 1987c). Up to 12 in. of sediment were removed from the lake bottom and disposed of in Sections 11 and 12 (Wingfield, 1977, in Ebasco, 1987c).

Because of flooding in Irondale Gulch through Lower Derby Lake in May 1973, an emergency overflow ditch (D5, Figure 1.4-5) was constructed south of the lake to carry overflow to the Rod and Gun Club Pond.

Lower Derby Lake can receive inflow from the Highline Lateral and the Uvalda Interceptor. As of 1982, Lower Derby Lake stored water used to maintain the water level in Ladora Lake. Lower Derby Lake is currently used for catch-and-release fishing (Ebasco, 1987c). The normal pool storage volume of the lake is 550 ac-ft with a surface area of 73 ac (USACE, 1987).

1.4.2.2.3 Ladora Lake

Ladora Lake, located in the central and south-central portion of Section 2 (Figure 1.4-1), was constructed for agricultural irrigation before RMA was constructed (Donnelly, 1986, in Ebasco Services, Inc. 1987c). In 1942 the lake was enlarged to increase its storage capacity for water used in the process water system. At this time the bottom was sealed with clay to reduce water seepage (Gatlin, 1960, Ebasco, 1987c), and the process water pumphouse located adjacent to Ladora Lake was constructed (Ebasco, 1987c).

Ladora Lake has undergone several modifications and repairs since 1942. The inlet ditch at the eastern end of the lake was deepened in 1957 (Donnelly, 1963, in Ebasco, 1987c). In 1963, ditch D15B was constructed along the northwestern edge of Lower Derby Lake to carry return cooling water through a pipe along the bottom of Lower Derby Lake and into the sluice box (Ladora Weir) located between Lower Derby Lake and Ladora Lake (Donnelly, 1963, in Ebasco, 1987c). The lake was drained during 1964 and 1965, and the upper 6 to 12 in. of the lake bottom sediments were removed and disposed of in the north-central portion of Section 11 (Ebasco, Inc., 1987c). During the 1973 flood, water flowed over and damaged Ladora Lake's undefined western spillway. After 1975, overflows from Ladora Lake could no longer enter Lake Mary. A ditch (D6) was constructed to divert overflow around the south end of Lake Mary, directing it north along the east side of C Street, and then to the west under C Street to an overflow basin in the eastern portion of Section 3 (Figure 1.4-5). This ditch and a new spillway were reconstructed during the summer of 1989. The normal pool storage volume of Ladora Lake is 341 ac-ft, with a surface area at that volume of 60 acres. Average water depth is estimated to be 5.7 ft.

1.4.2.2.4 Lake Mary

In 1960 the swampy area west of Ladora Lake in Section 2 (Figure 1.4-1) was excavated and a berm was constructed to create a 7-acre lake (Donnelly, 1986, in Ebasco, 1987c). Water was added and this early version of Lake Mary was stocked with fish. Several years later, parallel earthen mounds were constructed to partition the eastern portion of the lake into three areas for use in minnow-rearing. Shallow sections of the lake were dredged and tree stumps removed during 1967 (Mack, 1967, in Ebasco, 1987c). During 1974, Lake Mary was drained, enlarged slightly, and deepened to an average depth of 15 ft to enhance the quality of the water for the fish (Mullan, 1975; Schmidt, 1975; in Ebasco, 1987c). During this renovation, spillway ditch D6 was constructed to direct overflow from Ladora Lake around the southern edge of Lake Mary. Lake Mary was refilled with water from a deep well instead of from the industrial lakes to prevent possible contamination (MKE, 1987). Lake Mary can receive a regulated water supply pumped from several sources: three alluvial wells in Section 4, Ladora Lake, and the 1-million-gal potable water storage tank. A 4-in. steel siphon pipe located between Ladora Lake and Lake Mary was reopened in 1988 (Jim Green, Chief Facility Engineer, RMA, personal communication, 1990). Lake Mary occupies 9 acres at a normal pool storage volume (spillway crest) of 60 ac-ft (USACE, 1983b).

1.4.2.2.5 Rod and Gun Club Pond

The Rod and Gun Club Pond located in the north-central part of Section 12 is in a natural topographic depression south of Lower Derby Lake (Figure 1.4-1). The area occupied by the pond may have been excavated between 1965 and 1971, as indicated by aerial photographs (MKE, 1987). The shallow ditch that connects the Rod and Gun Club Pond to Lower Derby Lake was dug during the May 1973 flood to carry overflow from the lake. During 1977, water was pumped from Lower Derby Lake to the Rod and Gun Club Pond to maintain the pond's water level (Rocky Mountain Fisheries Consultants, Inc., 1978, in MKE, 1987); the pond has since lost water, although it receives runoff from a small catchment. When water levels are high enough, overflow from Lower Derby Lake can replenish the water in the pond. The Rod and Gun Club Pond can also receive overflow from the Uvalda Interceptor when the stage in the Uvalda Interceptor is high enough for water to flow through a low area in its bank. This overflow water moves across a field in an undefined channel before reaching the Rod and Gun Club Pond. The surface area of the pond when full has been estimated at 19.3 acres (Ebasco, 1986; in MKE, 1987). This includes the marshy area around the pond. The actual pond covers about 4.9 acres and has a volume of less than 15 ac-ft.

1.4.2.2.6 Havana Pond

Three natural depressions originally comprised Havana Pond. These original depressions are now nondistinct and one pool in the southwest portion of section 11 defines the pond. An earthen dam was

constructed at the north end of the three depressions in the early 1970s. The dam was built as part of the drainage plan for the Stapleton International Airport expansion project. The pond receives storm water runoff from two ditches, the Havana Interceptor and the Peoria Interceptor. The surface area of Havana Pond increases substantially during periods of intense precipitation (Ebasco, 1989b). An overflow spillway was installed at the north end of the pond in 1988 to allow for discharge into Sand Creek Lateral during periods of high water. Based on the WRI (Ebasco, et al., 1989a) storage volume information, an overflow of the pond would occur at a stage of 7.9 ft when the pond contains 202.6 ac-ft of water. On July 30, 1991 overflow occurred at the spillway for the first time since its construction.

1.4.2.3 Collection Basins

Six basins for the retention of process wastes, wastewater, or storm runoff were constructed on RMA within the South Platte Drainage Basin (Figure 1.4-1). These basins are natural topographic depressions which have been supplemented by berms and other structures. The topographic depressions associated with the basins have small catchment areas. Surface-water runoff within these catchments does not directly contribute to the flow of any major surface-water drainage at RMA.

The Basin A subcatchment in Section 36 has a total area of about 240 acres. The subcatchment includes the Basin A disposal area and portions of the South Plants industrial complex. The Basin A disposal area was originally a natural depression that was modified by embankments to provide greater storage for liquid process wastes (U.S. Army Chemical Warfare Service, 1945). In 1952 the impoundment dike was raised 5 ft to handle additional waste from the North Plants operations (Moloney, 1982). In 1956, the contents of Basin A were transferred to Basin F (PMCDIR, 1977).

The subcatchment receives runoff that is transported from the northern part of the South Plants industrial complex through the stormwater drainage system under December Seventh Avenue (USACE, 1984). Most runoff in this subcatchment collects in low areas and causes local ponding in Basin A, where it infiltrates, transpires, evaporates or remains in storage.

Surface-water discharge from the subcatchment occurs primarily along the small drainage on the northwest portion of Section 36, referred to as the Basin A ditch. Flow is from Basin A to Basin B, and subsequently out to Basins C, D and E (Blackwell, 1973). Runoff is contained within the basins and evaporates or infiltrates into the soil.

Basin B is in the northeast corner of Section 35, covers 1.77 acres, and is a modified natural topographic depression. A series of ditches connecting Basin A to Basins B, D and E was constructed in 1946. At that time, a culvert was built under Sand Creek Lateral in the ditch flowing out of Basin B to prevent overflow water from entering the Sand Creek Lateral. This ditch system was built to provide a controlled pathway for outflow in case the Basin A dam failed, and also to provide additional storage for liquid

waste overflows from Basin A (U.S. Army Chemical Warfare Service, 1946). A new Basin A runoff ditch was constructed in 1957 and was used until 1964. Drainage through this ditch can enter Basin B from the southeast. However, Basin B was dry in 1985, and has contained only a small marsh with limited catchment area since 1986 (CAPS, 1986).

Basin C is an unlined basin that was constructed in 1953 (ESE, 1987a) in a natural depression in the south-central portion of Section 26. It was designed as the primary overflow containment basin for Basin A wastes prior to construction of Basin F. Basin C covers about 78 acres at a spillway crest storage volume of 620 ac-ft (USACE, 1983c). In 1953, as part of the project for the construction of Basin C, the Army closed the culvert under the Sand Creek Lateral adjacent to the outfall ditch from Basin B, and modified this outfall to divert waste fluids overflowing from Basin B into the Sand Creek Lateral and ultimately into Basin C via a connecting ditch installed at headgate 41 (USACE, 1953). Concrete weirs and unlined ditches were also installed to connect Basins C, D and E (ESE, 1987). From late 1953 until the construction of Basin F in 1956, excess waste fluids from Basins A and B flowed via this pathway, first to Basin C, and then to Basins D and E (USACE, 1953). It is not known when the culvert under the Sand Creek Lateral was reopened after 1956. All waste fluid flowing into the basin was derived from overflow from Basins A and B or from surface drainage ditches in the South Plants that led into the Sand Creek Lateral (ESE, 1987). The basin was used for two months during the spring of 1957 while the liner in Basin F was undergoing repairs. In 1962, the Army installed a pump, a diversion box at the inlet to Sand Creek lateral near the basin's north embankment, and a series of ditches. The ditches led to the northern portions of the Sand Creek Lateral and were used to retain and transport fresh water to the wheat fields in Sections 23 and 24. Water was not stored in the basin until 1965 (RMA, 1962 and 1963, as cited in ESE 1987a). The basin was observed to be dry in 1986 (CAPS, 1986).

Basin D is located in south-central Section 26, south of Basin F and southwest of Basin C, and covers about 20 ac. A ditch directs overflow from the basin west into Basin E. Basin D is now dry, except after high precipitation.

Basin E covers 29.4 ac in the southwest portion of Section 26, southwest of Basin F and west of Basin D. The storage volume and drainage area of the basin are unknown. Flow is received from Basin D. There is no outflow. By 1980, all the fluids in Basin E had evaporated or infiltrated (ESE, 1986b). Basin E is now dry.

The Basin F subcatchment was located just north of the Sand Creek Lateral drainage, west of the First Creek drainage, and within the South Platte drainage area. Basin F was removed and the area was recontoured during the Interim Response Action (IRA) completed in 1989.

Basin F was a primary disposal site for liquid and chemical wastes at RMA from 1956 to 1981. The basin was roughly oval in shape, 2,900 ft wide at the north end and 1,600 ft wide at the south end. The total area was 92.7 acres and the maximum volume was 746 ac-ft (ESE, 1988c).

Basin F was considered a capture system (RCI, 1982) in which surface water remained in storage or evaporated. Recent construction has altered the drainage characteristics of this area. Although nearby Basins C, D and E have revegetated, Basin F contained wastes until the IRA was initiated in 1988. (Ebasco, et al., 1989a). As part of the IRA, Basin F was revegetated. The basin no longer contains contaminated liquid waste. A clay cap has been applied to the floor of the basin and also to the top of the waste pile. The basin is now dry. A monitoring station was installed in October 1989 to monitor flow from surface-water runoff from the Basin F IRA area.

1.5 PROCESS WATER AND SANITARY SEWER SYSTEM

RMA sewer system components that affect surface water are the process water system and the sanitary sewer system. The process water system is comprised of the lakes system, the South Plants closed-loop system, and the North Plants closed-loop system. The lakes system formerly supplied process water for the South Plants manufacturing processes, the administration area, and housing areas for fire protection. Water was pumped out of Ladora Lake and distributed to the various facilities. Water used in the South Plants area for cooling returned to the Derby Lakes. In 1964 a closed-loop system was created for industrial activities in the eastern South Plants area (Ebasco, August 1988c).

The South Plants closed-loop system used a cooling tower and storage reservoir, a pump station and an elevated storage tank. Cooling tower blowdown water was discharged to a sedimentation pond immediately south of the cooling tower. After treatment by sedimentation, the water was pumped back into the closed-loop system. Return water did not enter the lakes system; however, supplemental water was obtained from the lakes system.

In 1975 the closed-loop system using the cooling tower and sedimentation pond ceased operation (Stearns-Rogers Engineering, personal communication, 1989). The only activities in South Plants that currently require process water from the lakes system are in the power plant. The process water system also provides water for irrigation (lawn watering), and auxiliary water for fire protection. Water is drawn from Ladora Lake using a 75-horsepower pump operating at 30 gal/min. Cooling water from the power plant is discharged into a small ditch south of the power plant (Figure 1.4-5). This ditch connects to a series of east-west ditches that discharge into Sand Creek Lateral.

The process water distribution system of the lakes system was extended to the North Plants manufacturing complex in 1952 to provide fire protection and supplemental water for the North Plants closed-loop system. The North Plants closed-loop system used a cooling tower and an elevated storage tank with an

attached pump station. Process return water from the North Plants complex was not returned to the lakes system. Cooling tower blowdown water was discharged to the North Plants storm drainage system. This drainage network consisted of a ditch system that captured surface runoff, storm sewer drainage, and process-water discharge, and then directed it from the southern North Plants area to First Creek.

Circa 1980 the drainage network was modified to direct some surface-water runoff from the southeastern portion of the North Plants to a ditch that flowed north along the east margin of the facilities (Stout and Abbott, 1982). The ditch connecting to First Creek was modified. Ditch D 26B then had a starting point along the eastern fence and perimeter road (Figure 1.4-5). Ditch D 26A remained connected to the storm sewer drainage network in the southern North Plants area. No process water is currently discharged from North Plants, and the ditches in the area carry only storm sewer effluent and surface-water runoff.

Supplemental water for the lakes system is normally supplied by irrigation water from the Highline Lateral or stormwater from the Uvalda Interceptor. Water can also be supplied from wells in Section 4, or from the potable water system that is connected to the City of Denver water system for fire protection and irrigation. The process water system is designed to operate with the potable water system, so that the systems can be interchangeable during a breakdown or water supply problem (Ebasco Services, Inc., 1988c).

RMA surface-water flow is also affected by the sanitary sewer system. The sanitary sewer Interceptor Line originates near the north boundary of Section 1 in South Plants and terminates at the Sewage Treatment Plant in Section 24 (Figure 1.4-1). The sanitary sewer Interceptor Line collects and transmits domestic wastewater from the administration and railroad areas, the North Plants complex, and the South Plants manufacturing area (Ebasco, et al., 1988b). When it reaches the Sewage Treatment Plant, wastewater is filtered through sand and gravel and treated in a granulated active carbon and in-line ozonation system (Ebasco, et al., 1987a). Effluent is discharged into a ditch connected to First Creek in Section 24. Discharge from the facility is recorded continuously by a totalizing flow meter.

2.0 REVIEW OF RMA SURFACE-WATER INVESTIGATIONS

This section reviews the historical development of the surface-water program at RMA. The review documents previous surface-water program goals and accomplishments. Additional detailed information regarding the strategies, monitoring stations, field methods, and procedures used in pre-CMP programs is provided in Section 3. An assessment and comparison between pre-CMP data and FY88 and FY89 CMP data results is presented in Section 4.

The present surface-water monitoring program has evolved from a series of programs and studies originating in 1975. The first sampling program implemented at RMA used monitoring wells and surface-water sites within and around the Arsenal. Sampling was initiated because of organic solvents and phthalate esters detected in RMA wells by the Colorado Department of Health (CDH). It was believed that sources outside RMA might be contributing to the contamination. This was called the Revision I-360 Degree Monitoring Program (U.S. Army, 1977). Program participants included the U.S. Army, Shell Chemical Company and the CDH. The 360 Degree Monitoring Program was initiated in January 1976 and included 124 groundwater monitoring wells and surface-water sites on or adjacent to RMA (Table 2-1). Additionally, five off-post surface-water sites and 24 private wells were selected by the Tri-County District Health Department (ESE, 1986a). In November 1976 the program was revised, resulting in quarterly analyses for 12 surface-water locations on RMA and 10 off-post sites. Under this new program, identified as the Revision II-360 Degree Program, the network of off-post surface-water sites established in the original Revision I-360 Degree Program remained essentially the same (U.S. Army, 1977). With the closing of Shell Chemical Company's facilities at RMA in 1982, Shell's participation in the program was reduced (Ward, 1984). The Revision III-360 Degree Program, implemented in 1985, consisted of 11 off-post surface-water sampling sites (ESE, 1986a).

The first comprehensive monitoring effort directed at understanding surface-water flow at RMA was begun in 1982 by an Army contractor, Resource Consultants, Inc. (RCI). RCI installed the gaging equipment currently used at most stations at the Arsenal. From 1982 to 1984, 10 monitoring stations were constructed, as shown in Table 2-1. Stage and discharge data were collected and rating curves were developed. Flow measurements were not obtained at Highline Lateral and Basin A inflow, where rated structures existed. From 1982 to 1984, while RCI was conducting the surface-water gaging program, surface-water chemical sampling was being carried out concurrently under the Revision II - 360 Degree Monitoring Program. In 1984 an independent contractor (Bill Krupke), installed concrete control structures at five of the monitoring stations under the direction of U.S. Army Waterways Experimental Station. He also collected stage and discharge data throughout the network. This data were never reduced and no strip chart records are available.

Task 4 was initiated in 1985 as a coordinated surface-water quality and quantity monitoring program. A main objective of Task 4 was to develop a quality core database for Remedial Investigation/Feasibility

Table 2.0-1 Chronology of RMA Surface-Water Monitoring (Page 1 of 5)

Date	Monitoring Organizations	Program Name and Activities
January 1976 - November 1976	Tri-County Health Dept.; Colorado Dept. of Health; Shell Chemical Co.; RMA Personnel	Revision I-360° Program . Sample surface water and groundwater both on and off post
November 1976 - 1982	Tri-County Health Dept.; Colorado Dept. of Health; Shell Chemical Co.; RMA Personnel	Revision II-360° Program . Sample surface water and groundwater quarterly, both on and off post
1983 - 1985	Tri-County Health Dept.; Colorado Dept. of Health; RMA Personnel	Revision II-360° Program . Sample surface and groundwater quarterly, both on and off post
1981 - 1982	Resource Consultants, Inc.	. Delineate watersheds and major flow paths . Calculate a water balance based on estimated flows
Spring 1982	Resource Consultants, Inc.	. Install gaging stations at South First Creek, South Uvalda Interceptor, Basin A inflow, Ladora Weir, North Uvalda Interceptor (relocated) and South Plants Ditch . Monitor 7 gaging stations for stage and discharge

Table 2.0-1 Chronology of RMA Surface-Water Monitoring (Page 2 of 5)

Date	Monitoring Organizations	Program Name and Activities
October 1982 - September 1983	Resource Consultants, Inc.	. Install gaging stations on Peoria Interceptor, Havana Interceptor and North First Creek . Move North Uvalda station to current location . Install staff gage at Havana Pond . Monitor 10 gaging stations for stage and discharge
May - December 1984	Jack Dildine (Waterways Experiment Station); Bill Krupke (subcontractor)	. Install concrete control structures at South Uvalda, North Uvalda, South First Creek, North First Creek on-post and Peoria Interceptor
December 1985 - April 1986	ESE	Revision III-360° Program . Sample surface- and groundwater off-post
1985	ESE; Resource Consultants, Inc. (subcontractor)	Task 4 - Water Quantity/Quality Survey Program . Monitor 10 gaging stations for stage and discharge . Designate 30 sites for sampling . Install 2 rain gages on RMA

Table 2.0-1 Chronology of RMA Surface-Water Monitoring (Page 3 of 5)

Date	Monitoring Organizations	Program Name and Activities
September 1985 - February 1986	ESE; Resource Consultants, Inc. (subcontractor)	Task 4 - Initial Screening Program . Repair and rehabilitate existing recording stations . Install staff gage on Lake Mary . Monitor water-surface elevations weekly on Upper and Lower Derby, Ladora Lake and Lake Mary . Monitor 11 gaging stations for stage and discharge . Sample 16 on-post surface-water sites
December 1985 - January 1986	ESE; Resource Consultants, Inc. (subcontractor)	Task 4 - Final Screening Program . Monitor off-post recording station on North First Creek . Monitor 12 recording stations for stage and discharge . Monitor surface-water elevations on Upper and Lower Derby, Ladora Lake and Lake Mary weekly . Sample 19 on-post and 11 off-post surface-water sites during 3rd Quarter FY86 . Sample 21 on-post and 9 off-post surface-water sites during 4th Quarter FY86

Table 2.0-1 Chronology of RMA Surface-Water Monitoring (Page 4 of 5)

Date	Monitoring Organizations	Program Name and Activities
December 1986 - September 1987	ESE	Task 39 - Off-Post Remedial Investigation/Feasibility Study . Designate 11 off-post surface-water sites for sampling
March 1987 - November 1987	ESE Resource Consultants, Inc. (Subcontractor)	Task 44 . Monitor 12 recording stations for stage and discharge . Monitor water surface elevations on Upper and Lower Derby, Ladora Lake and Lake Mary . Designate 40 on- and off-post sites for quarterly sampling
April 1988 - September 1988	R.L. Stollar & Associates, Inc. Harding Lawson Associates (subcontractor)	Comprehensive Monitoring Program . Monitor 10 recording stations for stage and discharge (North First Creek station destroyed July 1987, North First Creek off-post station inoperative due to non-functioning control structure) . Monitor water surface elevations on Upper and Lower Derby, Ladora Lake, and Lake Mary . Monitor totalizing flow meter at Sewage Treatment Plant effluent discharge location . Designate 35 on- and off-post sites

Table 2.0-1 Chronology of RMA Surface-Water Monitoring (Page 5 of 5)

Date	Monitoring Organizations	Program Name and Activities
October 1988 - September 1989	R.L. Stollar & Associates, Inc. Harding Lawson Associates (subcontractor) Riverside Technology, Inc. (subcontractor)	Comprehensive Monitoring Program (FY89) . Continue FY88 Program . Add new monitoring stations and control at South First Creek, North First Creek, and First Creek Off-Post

Study analysis (ESE, 1988a). ESE managed the program, and RCI supported collection and interpretation of surface-water flow and lake level information. The goals of the surface-water portion of the Task 4 water quality and quantity survey were twofold. Separate efforts determined a surface-water mass balance for RMA, and tested water quality at 30 designated on-post sites (ESE, 1988a). The first phase of Task 4 was conducted under the Initial Screening Program (ISP) from September 1985 through February 1986. Initial efforts in the surface-water portion of the program addressed repair and rehabilitation of existing monitoring devices and recording stations. Sixteen on-post surface-water sites were sampled (ESE, 1987b).

Surface-water quantity and quality data continued to be gathered during the third and fourth quarters (spring and summer) of FY86 under Task 4. These results were reported in the Final Screening Program report (ESE, 1988a). The Final Screening Program was essentially the same as that developed for the ISP. As a baseline for future studies, a core database was maintained to track surface-water conditions, groundwater recharge, changes in contaminant migration, and the effects of expanding urbanization (ESE, 1988a). The surface-water quantity monitoring network used during the ISP was expanded by an off-post station on First Creek near Highway 2. The surface-water quality monitoring network (Table 2-1) was augmented by 46 potential on-post surface-water sampling sites and 11 potential off-post sites.

From December 1986 to September 1987, 11 off-post surface-water sites designated by the Task 4 Final Sampling Program were sampled under the direction of the Off-Post Remedial Investigation/Feasibility Study (Task 39). Task 39 was instituted to provide a remedial investigation/feasibility study for the area north and northwest of RMA.

Following Tasks 4 and 39, on-post and off-post surface-water monitoring activities continued to be directed by ESE under the new Task 44 contract awarded in March 1987. Task 44 operated under the core objectives of Task 4, with a broadened scope. The expanded program included monitoring changes in water quality, assessing distribution and concentration levels of contaminants, identifying areas of public exposure, and recommending modifications to the program (ESE, 1988b). The 12 gaging stations established during Task 4 were used during this monitoring period. Forty potential on- and off-post surface-water locations were designated for quarterly sampling. On-post locations corresponded to the sampling sites used during Task 4. Surface-water quantity and quality data were collected during high flow events if they fell within designated sampling periods.

As part of the Remedial Investigation program, the Water Remedial Investigation Report (Ebasco, 1989a) was recently created as a summary document of water-related programs at RMA. This report presents data and interpretations related to the surface-water system at RMA. Included in the document are discussions of water balances, surface-water/groundwater interactions, and historical surface-water quality data from fall 1985 to fall 1987.

During FY88 water quantity was monitored by Stollar using the network established by previous contractors. The network included 10 continuous recording stations, four lake stations monitored weekly and the Sewage Treatment Plant flow meter monitored weekly (Table 2-1). Instantaneous discharge measurements were obtained monthly at active stream stations. The water quantity database was expanded by reviewing and refining rating curves developed by previous contractors for each monitoring station. During FY89 the water quantity network established during FY88 was expanded with a new station at North First Creek near the north boundary in Section 24.

Water quality samples were obtained from the network established by previous contractors. Thirty-five on- and off-post water sample locations were used during FY88. Surface-water quality samples were collected during three high events at three locations. Suspended-load and bed load sediment were collected from on- and off-post locations and quantitatively and qualitatively analyzed.

Sample locations established during FY88 were used during FY89. Surface-water quality samples were collected from seven locations during three storms. Suspended-load sediment samples for quantitative analysis were collected along the southern reach of First Creek. Bottom sediment samples were collected throughout RMA for qualitative analysis.

3.0 SCOPE OF WORK AND DATA COLLECTION PROCEDURES

Monitoring and analysis of surface-water quantity and quality at RMA has evolved to meet changing conditions, including: 1) interim response actions, 2) technical improvements in data gathering equipment and procedures, and 3) man-made modifications to the flow system. Data collection also has been modified over the years in response to an increased understanding of the flow systems. The following describes the acquisition of water quality and quantity data at RMA from 1975-1987 (pre-CMP) and for 1988-1989 (CMP).

3.1 PRE-CMP SURFACE-WATER QUANTITY

In 1981, under contract from Stearns-Rogers Engineering and a purchase order from Computer Science Corporation, RCI started the first comprehensive study of the surface-water system at RMA. The study was designed to provide supplemental information on surface-water features for use in other investigations. A March 1982 report suggested upgrading two gaging stations and adding seven. This report attempted a water-balance calculation on the basis of estimated inflows. It recommended installation of a monitoring network to permit calculation of a more refined water balance (RCI, 1982). The data in the report were derived principally from published data and hydrologic analyses of several areas surrounding RMA. Watersheds and major drainages were defined. Watershed runoff estimates were computed empirically for 1971 through 1979 by using daily precipitation data from the weather station at Stapleton Airport.

In the spring of 1982, RCI installed gaging stations on South First Creek, South Uvalda Interceptor, Basin A inflow, Ladora Weir, North Uvalda Interceptor (relocated) and South Plants Ditch (RCI, 1983). A staff gage was placed in Havana Detention Pond (Table 2-1). A gaging station was then being used at Highline Lateral; RMA personnel took over responsibility for the station, which had been operated by Shell.

Between October 1982 and September 1983, additional gaging stations were installed at Peoria Interceptor, Havana Interceptor and North First Creek. The gaging station for North Uvalda Interceptor was moved for the second time, to its present location. Ten RMA stream and ditch gaging stations were monitored during that period by Army personnel. Ladora Lake, Lower Derby Lake and Havana Pond water levels were also recorded. The primary objective of the monitoring period was to complete an accurate, Arsenal-wide, annual water balance calculated from monthly water quantity measurements. This objective was hampered by data gaps, principally with regard to the lakes. Because of missing data and discrepancies in lake stage/volume relationships, the annual water balance computation used several estimates. RCI conducted the monthly reviews, reducing data and preparing the water balance. Rating curves were developed or updated for South First Creek, South Uvalda, Basin A inflow, and the South Plants Ditch (RCI, 1984).

From May through December of 1984, monitoring of flow and water levels at RMA was performed by Bill Krupke, who was contracted by the U.S. Army Waterways Experimental Station. Work included installing concrete control structures at South Uvalda, North Uvalda, South First Creek, North First Creek, Peoria Interceptor, and placing a Stevens Type F recorder at Havana Detention Pond to use with the existing staff gage.

ESE began managing the surface-water program under Task 4 in 1985 (Table 2-1). Data collected during the Task 4 Water Quantity and Quality Survey Program included water levels and flow measurements from 12 RMA monitoring stations, meter readings for water from Ladora Lake used as process water, monitoring outflow discharge of effluent at the Sewage Treatment Plant, and recording water-surface elevations on Upper Derby Lake, Lower Derby Lake, Ladora Lake and Lake Mary. Two rain gages were installed on RMA to aid in water balance computations. Lake levels were recorded weekly. Stream stages and Havana Pond water levels were measured continuously. In 1986, ESE established an additional station, First Creek Off-Post near Highway 2. This station consisted of a Stevens Type F recorder with a H-flume for channel control. As part of the quantity program, rating curves were to be modified and extended by using Hydraulic Engineering Center (HEC-2) procedures.

The surface-water network continued to be managed by ESE into 1987 under Task 4. Additional attempts were made to verify and extend stage-discharge rating curves for gaging locations at North and South First Creek, North and South Uvalda, Peoria Interceptor and Havana Interceptor. During 1987, no stations were established, and no modifications were made to the existing stations.

Other studies relating to the surface-water system at RMA include drainage basin analyses by Wright Water Engineers (WWE) (1988) and USACE (1983b, c, and d). WWE presented the results of a hydrologic analyses of First Creek and Irondale Gulch drainage basins that evaluated the hydrologic characteristics of the watersheds for existing conditions, and with or without the proposed new Denver Airport. Flood peaks and volumes were defined for various recurrent storm intervals.

USACE (1983a) prepared a drainage analysis for the upper Irondale Gulch and First Creek watersheds on RMA. Flood peaks and volumes for future development were defined, analyses of flooding problems were conducted, and recommendations for solving on-site drainage problems were made. The Corps conducted inspections of the lakes and their dams. In 1983 the four principal lake impoundments in the South Plants area — Havana Pond and disposal Basins C, D and F — were inspected. During this period disposal basins C and D were not in use. Additional inspections of Havana Pond, Ladora Lake and Lower Derby Lake were performed in 1986, 1987 and 1988. The inspection reports assessed the hydraulic, hydrologic, structural and geotechnical condition of the dams and impoundments. Hydraulic and hydrologic data incorporated in the reports include spillway, top-of-dam, and capacity-rating curves.

3.1.1 PRE-CMP SURFACE-WATER MONITORING NETWORK

Most of the gaging stations in the present surface-water monitoring network were installed between 1982 and 1985 (Table 3.1-1). The following is a more detailed description of each station as it evolved from installation to use as part of the surface-water element of the CMP.

- Highline Lateral — The Highline Lateral gaging station is located on the Highline Lateral, 20 ft south of Sixth Avenue in the northeast corner of Section 12 in Irondale Gulch Drainage Basin. It is situated along the unlined Highline Lateral, which delivers Army-owned shares of irrigation water from the South Platte River to Derby Lakes.

  Prior to March 1982, the station was operated by Shell Chemical Company. The station was equipped with an 8 in. X 12 in. Cipolletti Weir and a Stevens Manometer recorder. The manometer was in a protective housing mounted at the end of an open-ended, wooden-cased feeder channel. The wooden feeder channel was hydraulically connected to the main channel and was about 10 ft upstream from the weir.

  In the spring of 1982, the station was taken over by the Army, and the manometer recorder was replaced with a Stevens Type F recorder.

- South First Creek — The original South First Creek station was located on south First Creek in Section 5. This station monitored flow coming onto the RMA into the First Creek drainage basin.

  The station was installed in the spring of 1982 by RCI with a natural control section and equipped with a Stevens Type F recorder. The recorder was enclosed in a protective housing and mounted on top of a corrugated metal pipe stilling well.

  In 1984, under the direction of Bill Krupke, a concrete control structure consisting of a V-notch in a 12-in. wide concrete weir was placed in the channel.

- South Uvalda — The South Uvalda gaging station is located on the southern portion of the Uvalda Interceptor in south-central Section 12. It is situated in an unlined ditch and monitors surface and storm-sewer waters originating from off-post residential and industrial properties flowing on to RMA and the Irondale Gulch drainage basin.

  The station was installed in spring 1982 by RCI with a natural control section and equipped with a Stevens Type F recorder. The Stevens recorder was enclosed in a steel protective housing and mounted on top of a corrugated metal pipe stilling well. The

Table 3.1-1

Pre-CMP Surface-Water Quantity Monitoring Network

Station	Date of Installation	Type of Control	Type of Equipment
Highline Lateral	pre-1982 by Shell Spring 1982 operation taken over by the US Army	8 ft x 12 ft Cipolletti Weir	Stevens Manometer recorder and Stevens Type F recorder
South First Creek (Old)	Spring 1982 1984 abandoned 1988	natural control concrete control	Stevens Type F recorder and stilling well
South Uvalda	Spring 1982 1984	natural control V-notch in a 12-in wide concrete weir	Stevens Type F recorder and stilling well
Basin A	Spring 1982	90° V-notch	Stevens Type F recorder and stilling well
Ladora Weir	Spring 1982	standard suppressed rectangular weir	Stevens Type F recorder and a concrete basin used as a stilling well
North Uvalda	Spring 1982 moved to a new location in 1983 1984	natural control natural control concrete control structure	Stevens Type F recorder and stilling well
South Plants Ditch	Spring 1982 ? (later date)	two rectangular weir blades (redwood boards) 90° V-notch blades	Stevens Type F recorder and stilling well
Havana Pond	Spring 1982 1984		staff gage Stevens Type F recorder and stilling well
Peoria Interceptor	Summer 1983 1984 1985	natural control concrete control 2 ft x 12 ft redwood weir	Stevens Type F recorder and stilling well
Havana Interceptor	Summer 1983	concrete channel	Stevens Type F recorder and stilling well
North First Creek (Old)	1983 1984 abandoned 1987	natural control concrete control	Stevens Type F recorder and stilling well
First Creek Off-Post	1986	H-flume	Stevens Type F recorder and stilling well

stilling well was hydraulically connected to the active stream channel with 2-in. intake pipes.

In 1984, under the direction of Bill Krupke, a concrete control structure consisting of a V-notch in a 12-in. wide concrete weir was placed in the channel.

- Basin A — The Basin A gaging station is located in a drainage ditch in the southwest corner of Section 36, and is used to monitor storm sewer runoff from the South Plants area. Surface water flows past the structure into a concrete-lined channel connected to Basin A pond.

  The station was installed in the spring of 1982 by RCI with a 90° V-notch weir as a control structure, and was equipped with a Stevens Type F recorder. The recorder was enclosed in a protective housing and mounted on top of a corrugated metal pipe stilling well in the center of the ditch. A staff gage was later installed.

- Ladora Weir — The Ladora Weir gaging station is located in the southeast corner of Section 2 in the Irondale Gulch drainage basin. The station monitors flows in the channel coming out of Lower Derby Lake that can then be diverted into Ladora Lake or Sand Creek Lateral.

  The station was equipped with monitoring equipment in the spring of 1982 by RCI. The station consisted of a Stevens Type F recorder in a protective housing that was fitted onto a wooden deck. A concrete basin (stilling well) beneath the deck received flow from Lower Derby Lake. The control at the station was a standard suppressed rectangular weir made of two 2-in. wide planks on top of the concrete basin well.

- North Uvalda — The North Uvalda Station is located on the Highline Lateral ditch in the southeast corner of Section 1 in Irondale Gulch drainage basin, about 1,500 ft upstream of the inlet to Lower Derby Lake. The station was installed in the spring of 1982 by RCI with a natural control section. Channel work north of the initial site caused backwater that necessitated moving the station to a new location in 1983.

  During 1984, under the direction of Bill Krupke, a small concrete control structure was placed in the channel at the new location. The new station consisted of a Stevens Type F recorder enclosed in a protective housing mounted on a corrugated metal pipe stilling well. The stilling well was hydraulically connected to the active stream channel by two 2-in. intake pipes.

- South Plants Ditch — The South Plants Ditch gaging station is located near the center of Section 1 in the Irondale Gulch drainage basin at a diversion structure that can monitor flow from the South Plants area, that is directed to either the east or west end of Lower Derby Lake.

  The station was installed in the spring of 1982 by RCI. The diversion structure consisted of two rectangular weir blades made of 10-ft-wide 2 in. x 8 in. redwood boards. The station was also equipped with a Stevens Type F recorder enclosed in a protective housing and mounted atop a corrugated metal pipe stilling well. The stilling well is hydraulically connected to the ditch with 2-in. intake pipes. At an unknown date, the station was retrofitted with 90° V-notch weirs.

- Havana Pond — The Havana Pond gaging station is located adjacent to the earthen embankment on the north side of Havana Pond near the center of Section 11 in the Irondale Gulch drainage basin. The pond is used to store surface and storm runoff from the Havana and Peoria Interceptors. Initial monitoring began on Havana Pond in spring 1982. The only gaging equipment was a staff gage in the pond.

  In 1984, under the direction of Bill Krupke, a continuous water-level recording station was installed. The station consisted of a Stevens Type F recorder enclosed in a protective housing and mounted on top of a corrugated metal pipe stilling well. The stilling well was hydraulically connected to the pond.

- Peoria Interceptor — The Peoria Interceptor gaging station is located near the southern boundary of RMA, in the southwest quarter of Section 11. The station is designed to monitor surface water flowing from the south onto RMA. It is situated in an unlined ditch designed to carry surface and storm-sewer runoff from the off-post industrial area to Havana Pond.

  The station was installed in the summer of 1983 by RCI with a natural control section and equipped with a Stevens Type F recorder enclosed in a protective housing and mounted on top of a stilling well. The stilling well was hydraulically connected to the active stream channel with 2-in. intake pipes.

  In 1984, under the direction of Bill Krupke, a concrete control structure was placed in the channel. During 1985, the control structure was submerged by backwater from Havana Pond. To reduce the effects of the submergence, a 2-ft high 12-ft wide rectangular, redwood weir was installed by RCI. To ensure stability, gabions were

embedded in the banks on either side of the weir. Riprap over filter fabric was placed on the upstream and downstream aprons.

- Havana Interceptor — The Havana Interceptor gaging station is located near the southern boundary of RMA in the southwest corner of Section 11. The purpose of the station is to monitor surface water flowing from the south onto RMA and into the Irondale Gulch drainage basin. The Interceptor is a concrete-lined channel designed to carry surface runoff and stormwater to Havana Pond from a portion of Stapleton Airport and from commercial properties south of RMA.

  The station was installed in 1983 by RCI with a Stevens Type F recorder enclosed in a protective housing mounted on top of a corrugated metal pipe stilling well. The entire structure was suspended over the center of the concrete channel from a bridge constructed of two parallel telephone pole segments.

- North First Creek — The original North First Creek station was a natural control station located in Section 24 just downstream from the creek's confluence with the sewage treatment plant effluent channel.

  The station was installed in 1983 by RCI with a Stevens Type F recorder enclosed in a protective housing that was mounted on a corrugated metal pipe stilling well. The stilling well was hydraulically connected to the stream by 2-in. intake pipes.

  During WY82-83, stream channel was cut below the station recording level by high-intensity storms and associated flooding. In 1984, under the direction of Bill Krupke, a concrete control structure was placed in the channel. Because the station repeatedly washed out below the structure, both ends were stabilized using gabions and upstream and downstream riprap aprons. The station was temporarily abandoned in 1984. Strip Chart records indicate the station was again in operation in October 8, 1985. Flow records extend to July 1987 when the stilling well was destroyed during construction activities in the area (ESE, 1988d).

- First Creek Off-Post — The First Creek Off-Post monitoring station is located about one-half mile north of RMA's northern boundary and directly southeast of Highway 2 in the First Creek drainage basin. This station is used to monitor surface-water flow between the North First Creek station and First Creek Off-Post stations.

  The station was installed in 1986 by ESE with an H-flume as a control structure and equipped with a Stevens Type F recorder. The Stevens recorder was enclosed in a steel

protective housing and mounted on top of a stilling well that was hydraulically connected to the active stream channel.

3.1.1.1 Strip Chart Procedures and Equipment

Historical stream stage data were collected using Stevens Type F water level recorders attached to a float, beaded wire and pulley. These analog recorders produce a graphic plot of stream stage as a continuous function of time. The water-level recorders were typically located in instrument shelters resting on top of 24-in. corrugated metal pipe stilling wells. The stilling wells were either in stream or set into the banks and hydraulically connected to the stream channel with intake pipes or by a short, perpendicular ditch. The stilling wells that were installed in the channel banks had concrete-sealed bottoms to prevent the intrusion of groundwater. During the periods of data collection, the stations were visited weekly to change out the strip charts, check recorder operations, and calibrate recorders to an external staff gage.

3.1.1.2 Discharge Measurement Procedures and Computation of Discharge Data

Discharge measurements were randomly conducted at surface-water monitoring stations on RMA as part of the pre-CMP rating curve development program. The majority of the flow measurements were performed from 1982 to 1986 with a Marsh-McBirney electromagnetic flow meter. Discharge values were obtained by using the United States Geological Survey (USGS) midsection method (Rantz, 1982) with which the section velocities are converted to a total discharge. Marsh-McBirney measurements were obtained from the Havana Interceptor, Peoria Interceptor, Ladora Weir, South Uvalda, North Uvalda, Highline Lateral, South First Creek and the First Creek Off-Post stations.

A Parshall Flume was also used from 1982 to 1986 at some stations to obtain low-flow discharges. The Parshall Flume is an empirically rated, portable structure from which discharge values can be readily obtained. Parshall Flume measurements were performed at North Uvalda, North First Creek, South First Creek, and Havana Interceptor.

3.1.1.3 Rating Curve Development Procedures

Available historical reports yield very little information regarding the procedures used to develop rating curves. Documented, detailed procedures were not available in the literature pertaining to the pre-CMP RMA surface-water gaging program. As part of the initial effort by RCI to collect surface-water flow data in 1982, rating curves were developed, but were empirical and had to be verified by additional instant discharge measurements (RCI, 1983). These original rating curves were developed using actual measurements of instantaneous discharge and cross-sectional areas at various stages (RCI, 1984). These rating curves were used for stage data reductions through September 1983. Documentation of data reduction and rating curve development are not available for WY84 and WY85.

As the surface-water program evolved and the number of gaging stations increased, each surface-water gaging station was classified. One group included the stations with sharp-crested weirs, while the other group included all the natural channel stations equipped with control structures to stabilize the channel bottoms. The rating curves for the sharp-crested weirs used experimentally derived equations that relate the stage to discharge. Since these ratings were experimentally derived for the type of weir being used, RCI suggested that no additional rating development was required. The stations included in this group were Ladora Weir, South Plants Ditch, Highline Lateral, Basin A, and First Creek Off-Post. The other group, consisting of Peoria Interceptor, Havana Interceptor, South Uvalda, North Uvalda, South First Creek, and North First Creek, used instant stage-discharge measurements to fit a curve that describes the stage-discharge relationship at each station. RCI also suggested use of HEC-2 program to extrapolate the rating curves beyond the verified sections developed with instant stage-discharge measurements (RCI, 1986a). These revised rating curves were used for stage data reduction for October 1985 through September 1986.

The Water Remedial Investigation Report (WRIR), the final effort before the Comprehensive Monitoring Program, reported that the Remedial Investigation (RI) programs at RMA used the procedures outlined in the National Handbook of Recommended Methods for Water-Data Acquisition (USGS, 1977) to construct rating curves. This handbook states that stage-discharge relationships are usually developed experimentally from measurements of stage and discharge. The handbook further describes the methodology used to perform a graphical analysis of the stage-discharge measurements and methods to extrapolate the ratings beyond the range of measured stages and discharges. The revised rating curves were used for stage data reduction for flow data from October 1986 through November 1987. A comparison of the discharge data reported by RCI (RCI, 1986) for October 1985 to September 1986 and that reported in the Water Remedial Investigations WRI (Ebasco, 1989a) for that period shows a discrepancy between the two data sets. Apparently the revised rating curves developed by ESE were used to recalculate the WY86 flow data. The WRI provides streamflow data from October 1985 through November 1987.

3.1.1.4 Stream Stage and Discharge Data Computation

The Pre-CMP surface-water monitoring program at RMA used 12 Stevens Type F water-level recorders. Data recorded by the Stevens recorders are represented as a line on a chart depicting the stream stage as a continuous function of time. The X-axis on the chart represents time. All the RMA recorders were equipped with 8-day clocks. This makes every major division on the X-axis equal to one day with the smallest division representing two hours.

The Y-axis represented stream stage. The recorders at RMA were geared so that for each foot that the float traveled, the recorder pen recorded one-fifth ft of travel. This made each major chart division 0.5

ft and each small division 0.05 foot. The hourly values were consequently reduced to the nearest 0.05 foot.

The first step in the data reduction was estimating the stage to the nearest 0.05 ft for each hour of each day. It is unclear how the the hourly stages were interpreted (i.e., average values or maximum values). These hourly stages were then converted into hourly discharges with a rating curve, which is merely a curve relating stream stage to discharge. The hourly discharge values for each day were averaged and converted from cubic feet per second to acre-feet per day. The daily flow values were summed to obtain weekly and monthly values. Computers were used to convert hourly stages into discharge values. These procedures remained consistent throughout the pre-CMP stage and discharge data computations.

3.1.2 Acquisition of Lake and Pond Data

Shell Chemical Company monitored lake levels at RMA from 1952 to 1982. Stage-volume relationship curves were used by Shell in water volume calculations for Ladora, Upper Derby and Lower Derby Lakes. Subsequently, Stearns-Rogers Engineering has taken over operations and maintenance of utility systems. Stearns-Rogers (now United Engineers and Constructors) has recorded staff gage readings on the lakes 6-9 times daily over the years and reported lake volume calculation results to the RMA facilities engineer to assist in water management decisions.

Between 1964 and 1965, Lower Derby, Upper Derby, and Ladora Lake were drained and the lake bottom was excavated to remove contaminated sediment. Six to 12 in. of lake bottom sediment was removed (Ebasco, 1987c). Years later, estimates of more accurate stage-volume relationship curves were developed by RCI and presented in a report Review and Proposed Revision of Stage-Volume Curves for RMA's Lower Lakes (1986b). The original stage-area and stage-volume curves developed for the lakes (Whitman et al., 1943) were used by ESE to create stage-area and stage-volume tables. These tables were used to compute the lake volume data presented in the WRI (Ebasco, 1989a). This lake volume information was also used by ESE to conduct a water balance analysis of the lakes. The stage-volume relationship tables developed by ESE and presented in the WRI for Lower Derby, Upper Derby, and Ladora Lake have been used to calculate the lake volume data presented in the CMP annual surface-water data assessment reports.

Removal of lake bottom sediments circa 1964, and subsequent sedimentation in the lakes has probably altered the original area and volume relationships. However, the originally defined relationships are still being used as the best available data.

Stage-area and stage-volume curves for Havana Pond were developed by RCI in a 1985 survey. A tabulation of stage-area and stage-volume relationships for Havana Pond was presented in RCI's WRI Report (Ebasco, 1989a). Water volume and water balance calculations for Havana Pond presented in the

WRI Report for 1985-1987 relied on these tables. Water volume calculations for Havana Pond presented in the FY88 and FY89 CMP annual surface-water report were derived from the stage-volume relationship tables in the WRI.

3.1.3 Sewage Treatment Plant Discharge Data

The sewage treatment plant was constructed in 1942 for domestic sewage. The plant was designed on the basis of a 4-hour detention period at a flow rate of 420,000 gallons per day (Ebasco, 1989a). In 1979, a prefiltration unit, a carbon filtration unit, and a tertiary treatment system were added. The sewage treatment plant effluent was then discharged into a ditch connected to First Creek (Ebasco, 1987d). Flow meter readings taken from the Sewage Treatment Plant by RMA engineering personnel were compiled and converted to gallons per month by ESE (Ebasco, 1989a) for October 1985 to November 1987. This information is provided in the WRI Report (Appendix B, Ebasco, 1989a). Flow meter readings were collected weekly and on the first of the month by ESE. Monthly water volumes, in gallons, were obtained by subtracting first-of-the-month readings from end-of-the-month readings (Ebasco, 1989a). The average flow for this period was calculated to be 10 ac-ft/month. RMA engineers have collected discharge flow meter readings at the Sewage Treatment Plant using a Neptune totalizing flow meter since 1985. Prior to 1985 the method of recording discharge could not be confirmed. RMA engineering and maintenance personnel were responsible for gathering discharge data from the Sewage Treatment Plant before 1985, but the records of discharge measurement procedures and flow values for that period could not be located.

3.1.4 Meteorological Data

As part of the first comprehensive surface-water hydrologic study at RMA, precipitation data were gathered by RCI (1982) for a watershed runoff evaluation. The precipitation data for the study was taken from the Denver Weather Station at Stapleton Airport. Total monthly precipitation was tabulated for January 1977 to December 1981. The Stapleton precipitation data were used because the site is close to RMA, and the meteorological records are relatively long and complete. RCI reported in 1982 that a precipitation recording station in the northwest portion of RMA once was operational, but data were unavailable after June 1977. Since precipitation values used in the watershed runoff study had been taken from the Stapleton Weather Station, it was decided that the temperature data would also be derived from Stapleton.

Stapleton precipitation data were also used by RCI in a water inventory analysis conducted on three of the RMA lakes from January through October 1982 (RCI, 1983). It was noted in this report that there were several unofficial reports of excessive rainfall in the area of RMA, but Stapleton showed near normal amounts of precipitation. An additional component to the water inventory analysis was added for

this period. Pan evaporation measurements recorded at Cherry Creek Reservoir by USACE were used to determine evaporation values to be applied to the lakes.

In RCI's Annual Surface-Water Data Report for October 1, 1985 to September 30, 1986, precipitation values from three sources were used. Rainfall was recorded from two tipping bucket recording rain gages which had recently been installed on-post, and from the weather station at Stapleton Airport. The precipitation data used in the water balance calculations was derived by averaging daily rain values recorded at the three stations. Monthly precipitation values from Brighton and Northglenn were also reported for comparison, but were not used in the water balance calculations.

Precipitation and evaporation data used in water balance calculations for October 1985 through December 1987 are presented in the WRI (Ebasco, 1989a). The precipitation monitoring network consisted of an off-post station operated by the National Weather Service (NWS) at Stapleton Airport and two on-post stations previously installed by RCI and operated by ESE (Ebasco, 1989a). The two on-post stations were equipped with Weathertronics Model 6010 tipping bucket rain gages. Data were recorded on a Model 6113 Event Recorder Chart. One rain gage was located in South Plants along D Street and the other at the Sewage Treatment Plant. Daily precipitation data were taken from the on-post gage charts and averaged with Stapleton Airport data to obtain precipitation measurements in inches. Average monthly precipitation data for October 1985 to December 1987 are presented in Appendix B of the WRI Report (Ebasco, 1989a).

Evaporation values applied to the RMA lakes for water balance calculations conducted by ESE were based on pan evaporation data for Cherry Creek Reservoir. The Cherry Creek data were collected using a Class A pan and obtained by USACE (1987). Pan and lake evaporation data are supplied in Appendix B of the WRI (Ebasco, 1989a).

3.2 CMP SURFACE-WATER QUANTITY

This section discusses the procedures, strategies, and equipment used to acquire surface-water quantity data during FY88 and FY89 for the CMP surface-water component. Stage and instantaneous discharge data were obtained from existing and new RMA surface-water monitoring stations (Figure 3.2-1). These stations had been constructed for previous surface-water monitoring programs and reconstructed during the FY88-89 surface-water program to monitor surface water flowing onto and off of RMA (Table 3.2-1). The water quantity assessment undertaken by the surface water CMP is summarized in monthly water quantity data (RLSA, 1990a, Appendix A; RLSA, 1990b, Appendix A) and is used in remediation efforts at RMA. The quantity of water that enters and exits RMA in the form of precipitation, surface runoff, evaporation and operational use is used to determine the effects on ground water at RMA and to develop plans for surface water management. Figure 3.2-1 shows the locations of each surface-water

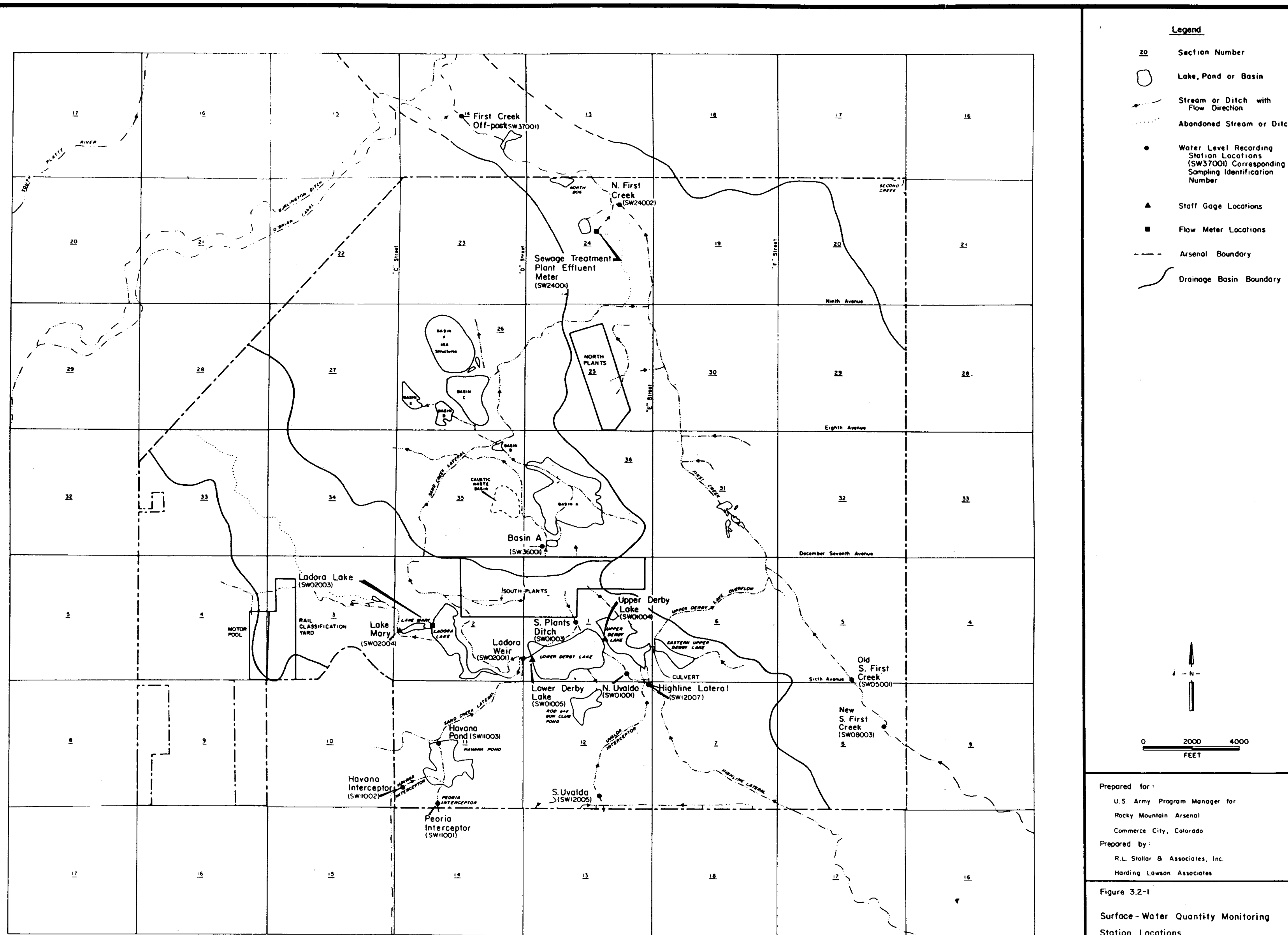

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Figure 3.2-1
Surface-Water Quantity Monitoring Station Locations

CMP SW FY90H

Table 3.2-1 Evolution of Surface-Water Monitoring Stations (Page 1 of 2)

Location	Installation Date	Type	Equipment Installer	Reference
Highline Lateral	Unknown	Manometer Level Recorder Cipolletti Weir	Unknown	RCI, 1983
	Spring 1982	Stevens Type F Recorder	RCI	RCI, 1983
South First Creek (old)	Spring 1982	Stevens Type F Recorder	RCI	RCI, 1983
	1984	Concrete Control Structure	Krupke	Unknown
	Sept 1988	Abandoned		
South First Creek (new)	Oct 1988	Concrete V-notch Weir	RLSA	
	March 1989	Stevens Type F Recorder Data Logger/Bubbler System	RLSA	
South Uvalda	Spring 1982	Stevens Type F Recorder	RCI	RCI, 1983
	1984	Concrete Control Structure	Krupke	Unknown
	March 1989	Data Logger/Bubbler System	RLSA	
Basin A	Spring 1982	Stevens Type F Recorder 90° V-notch Weir	RCI	RCI, 1983
	March 1989	Datapod Recorder	RLSA	
Ladora Weir	Spring 1982	Stevens Type F Recorder Standard Suppressed Rectangular Weir	RCI	RCI, 1983
	March 1989	Datapod Recorder	RLSA	
North Uvalda	Spring 1982	Stevens Type F Recorder	RCI	RCI, 1983
	1983	Station Moved	RCI	RCI, 1984
	1984	Concrete Control Structure	Krupke	Unknown
	March 1989	Datapod Recorder	RLSA	
South Plants Ditch	Spring 1982	Stevens Type F Recorder Rectangular Weir	RCI	RCI, 1983
	Unknown	90° V-notch Weir		
Havana Pond	Spring 1982	Staff Gage	RCI	RCI, 1983
	1984	Stevens Type F Recorder	Krupke	Unknown
	March 1989	Datapod Recorder	RLSA	
Peoria Interceptor	1983	Stevens Type F Recorder	RCI	RCI, 1984
	1984	Control Structure	Krupke	Unknown
	March 1989	Datapod Recorder	RLSA	
Havana Interceptor	1983	Stevens Type F Recorder	RCI	RCI, 1984
	March 1989	Stevens Recorder & Stilling Well Removed	RLSA	
	April 1989	Data Logger/Bubbler System	RLSA	
North First Creek (old)	1983	Stevens Type F Recorder	RCI	RCI, 1984
	1984	Concrete Control Structure	Krupke	Unknown
	July 1987	Abandoned		

Table 3.2-1 Evolution of Surface-Water Monitoring Stations (Page 2 of 2)

Location	Installation Date	Type	Equipment Installer	Reference
North First Creek (new)	Oct 1988	Concrete V-notch Weir	RLSA	
	March 1989	Stevens Type F Recorder	RLSA	
		Data Logger/Bubbler System		
First Creek Off-Post	1986	H-Flume	ESE	
		Stevens Type F Recorder		
	May 1989	Above Removed	RLSA	
	June 1989	Concrete Triangular-throated Flume	RLSA	
		Stevens Type F Recorder		
		Datapod Recorder		
Ladora Lake	Unknown	Staff Gage	Unknown	Unknown
	Unknown	Flow Meter	Unknown	Unknown
Sewage Treatment	Unknown	Flow Meter	Unknown	Unknown
Upper Derby Lake	Unknown	Staff Gage	Unknown	Unknown
Lower Derby Lake	Unknown	Staff Gage	Unknown	Unknown
Lake Mary	1985	Style C Staff Gage	ESE	Ebasco Svcs Inc., 1989a

RCI = Resource Consultants Inc.
ESE = Environmental Sciences and Engineering, Inc.
RLSA = R.L. Stollar and Associates, Inc.

quantity monitoring station and its relationship to the major RMA drainage basins described in Section 1.4.1. A single notation system was developed for the surface-water CMP to identify both stream discharge monitoring stations and water-quality sampling stations. Each monitoring station was assigned a corresponding water-quality number, as shown on Figure 3.2-2.

3.2.1 CMP SURFACE-WATER MONITORING NETWORK

This section describes the surface-water quantity monitoring stations used for the CMP and is subdivided into major drainage basins monitored on RMA. First Creek, Irondale Gulch and South Platte drainage basins each have surface-water quantity monitoring stations. Second Creek Drainage Basin and Sand Creek Drainage Basin do not have surface-water quantity monitoring stations because significant flows do not occur on RMA within these areas.

Each stream, lake, pond and diversion monitoring station was equipped, constructed and strategically located by previous contractors and by Stollar surface-water CMP personnel to accurately monitor surface-water volumes for use in water management and remediation efforts. This section describes the equipment and controls now used in the CMP and the surface water characteristically monitored at each station in the major drainage basins described in Section 1.4.1 (Table 3.2-2).

Surface-water quantity monitoring under the CMP was conducted during WY88 at 16 monitoring stations and in WY89 at 17 monitoring stations in three major drainage basins on RMA (Figure 3.2-1). Surface-water quantity monitoring activities included weekly operation and maintenance of continuous gage recording stations, and monthly instantaneous discharge measurements at sites with active streamflow. In addition, weekly staff gage readings were recorded at all stream and lake monitoring stations and the flow at the Sewage Treatment Plant in Section 24 was observed weekly. Summaries of the activities at each monitoring station during WY88 and WY89 in the three major drainage basins on RMA are provided in Table 3.2-1 of the FY88 and FY89 Surface-Water Data Assessment Report (SWDAR) (RLSA, 1990a and 1990b).

3.2.1.1 Irondale Gulch Drainage Basin

The Irondale Gulch Drainage Basin is located in the southwestern half of RMA, and is bordered by the South Platte and First Creek drainage basins to the northeast and by the Sand Creek Drainage Basin to the southwest (Figure 1.4-1). Included in the Irondale Gulch Drainage Basin is a portion of the Sand Creek Lateral Subdrainage Basin (Figure 1.4-1). Irondale Gulch Drainage Basin accepts surface-water flow from Havana Interceptor, Peoria Interceptor, Uvalda Interceptor, and Highline Lateral. The surface-water from these sources enters the drainage from the southern border of RMA and is directed to either Havana Pond or the South Plants Lakes. Flow can also be diverted to the Sand Creek Lateral subdrainage basin via Ladora Weir and/or Havana Pond. There is not a defined natural stream

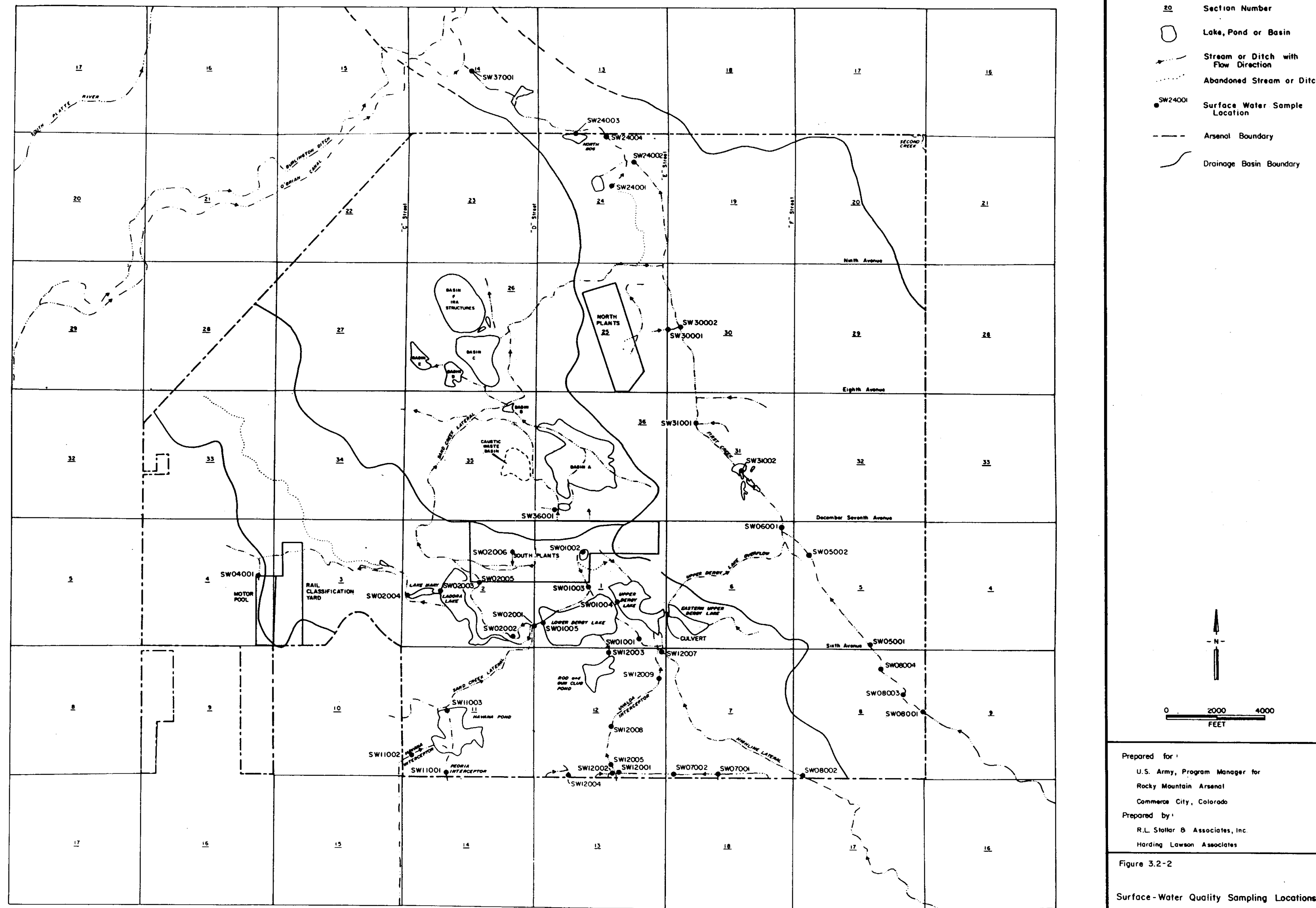

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Figure 3.2-2

Surface-Water Quality Sampling Locations

CMP SW FY90H

Table 3.2-2 CMP Surface-Water Monitoring Network (Page 1 of 2)

Site	Monitoring Equipment
Irondale Gulch Drainage Basin	
Havana Interceptor (SW11002)	Concrete Lined Channel Control and CR-10 Data Logger/Bubbler System
Peoria Interceptor (SW11001)	90° V-notch Weir Compound Control, Stevens Type F Recorder, Style C Staff Gage, DP115 Datapod (10/1/89-12/14/89), and CR-10 Data Logger/Bubbler System (12/14/89-present)
Ladora Weir (SW02001)	Rectangular Weir Section Control, Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod
South Uvalda Interceptor (SW12005)	Concrete V-notch Weir Compound Control, Stevens Type F Recorder, Style C Staff Gage, and CR-10 Data Logger/Bubbler System
North Uvalda Interceptor (SW01001)	Concrete Weir Compound Control, Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod
Highline Lateral (SW12007)	Cipolletti Weir Section Control, Stevens Type F Recorder, and Style C Staff Gage
South Plants Ditch (SW01003)	Sharp-crested V-notch Compound Control Weirs, Stevens Type F Recorder, and Style C Staff Gage
Havana Pond (SW11003)	Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod
Upper Derby Lake (SW01004)	Staff Gage
Lower Derby Lake (SW01005)	Staff Gage
Ladora Lake (SW02003)	Staff Gage
Lake Mary (SW02004)	Style C Staff Gage
First Creek Drainage Basin	
South First Creek (SW08003)	Concrete V-notch Weir Compound Control, Stevens Type F Recorder, Style C Staff Gage, and CR-10 Data Logger/Bubbler System

Table 3.2-2 CMP Surface-Water Monitoring Network (Page 2 of 2)

Site	Monitoring Equipment
North First Creek (SW24002)	Concrete V-notch Weir Compound Control, Stevens Type F Recorder, Style C Staff Gage, and CR-10 Data Logger/Bubbler System
First Creek Off-Post (SW37001)	Concrete Triangular-throated Flume Control, Stevens Type F Recorder, DP115 Datapod, and Style C Staff Gage
Sewage Treatment Plant (SW24001)	Totalizing Flow Meter
<u>South Platte Drainage Basin</u>	
Basin A Inflow (SW36001)	90° V-notch Weir Section Control, Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod

channel that exits RMA within the Irondale Gulch drainage basin. The drainage basin does extend from RMA along its northwestern border.

Twelve monitoring stations are located in the Irondale Gulch Drainage Basin (Figure 3.2-1) and have been used during FY88 and FY89 of the CMP. Stream monitoring stations include Havana Interceptor (SW11002), Peoria Interceptor (SW11001), Ladora Weir (SW02001), South Uvalda (SW12005), North Uvalda (SW01001), Highline Lateral (SW12007) and South Plants Ditch (SW01003). Lake and pond monitoring stations include Havana Pond (SW11003), Upper Derby Lake (SW01004), Lower Derby Lake (SW01005), Ladora Lake (SW02003) and Lake Mary (SW02004). Monitoring equipment that was in service at the surface-water gaging stations within Irondale Gulch drainage basin as of the end of FY89 is listed in Table 3.2-2.

3.2.1.1.1 Havana Interceptor (SW11002)

The Havana Interceptor gaging station is located near the southern boundary of RMA in the southwest corner of Section 11 (Figure 3.2-1). The purpose of the station is to monitor surface water flowing from the south onto RMA and into the Irondale Gulch drainage basin. The Interceptor is a concrete-lined channel and is designed to carry surface runoff and stormwater flowing to Havana Pond from a portion of Stapleton Airport and from commercial properties located south of RMA (Figure 3.2-1). The station was equipped with a Campbell Scientific CR-10 data logger and bubbler system in April 1989. The CR-10 data logger and a nitrogen cylinder for the bubbler system are housed in a wooden storage shed at the station. Staff gage measurements are taken by placing a metal tape measure next to the copper bubbler line in the channel bottom. Prior to the installation of the data logger, the station was equipped with a Stevens Type F Recorder mounted on top of a corrugated metal pipe stilling well. The entire structure was suspended over the center of the concrete channel from a bridge constructed of two parallel telephone pole segments. Attached to the stilling well was a Style C porcelain-enameled iron staff gage. The stilling well, Stevens recorder and staff gage were removed in March 1989. The channel control structure at the station is a concrete trapezoid. There are no additional control structures near the gaging station.

Before the Stevens Type F recorder and stilling well were removed, the station required an abnormal amount of maintenance due to accumulation of debris around the stilling well. The water quantity record was also corrupted because the stilling well obstructed the channel's normal flow. In its present configuration, however, the station requires minimal maintenance and is capable of providing water quantity records throughout the winter months when intermittent flow occurs during thawing. The nitrogen tank for the CR-10 bubbler system is replaced when tank pressure drops to less than 200 psi, and the CR-10's battery is replaced when it drops below 12 volts. The RAM-pack storage module on the data logger can be changed monthly or data can be downloaded directly to a IBM-compatible personal computer.

3.2.1.1.2 Peoria Interceptor (SW11001)

The Peoria Interceptor gaging station is located near the southern boundary of RMA, in the southwest quarter of Section 11 (Figure 3.2-1). The purpose of the station is to monitor surface water flowing from the south onto the RMA Irondale Gulch drainage basin. It is situated in an unlined ditch designed to carry surface and storm sewer runoff from the off-post industrial area to Havana Pond, as described in Section 2.3. The station is equipped with a Stevens Type F recorder. In October 1989, an Omnidata International DP115 datapod was added to the system. The datapod works with a potentiometer which with the Stevens recorder sits on top of a corrugated metal pipe stilling well. The well is connected hydraulically to the active stream channel by 2-in. intake pipes. In December 1989, a CR-10 data logger/bubbler system was substituted for the datapod system. The Stevens recorder is still being run at the same time as the data logger. A Style C staff gage is attached to the stilling well. The compound control structure at the station is a 90° V-notch steel plate weir attached to a narrow plank positioned perpendicular to flow and embedded in the banks on both sides of the channel.

The problems at this station are an accumulation of debris, vegetation overgrowth, and backwatering at the control. Trash is removed periodically, and vegetation overgrowth must be removed annually. A backwater condition exists at this station when the water exceeds 4.0 ft on the Havana Pond staff gage during moderate storms, resulting in the loss of some flow data. The weir was refabricated during April 1989 to correct leaking through, beneath, and around the old weir.

3.2.1.1.3 Havana Pond (SW11003)

The Havana Pond gaging station is located adjacent to the earthen embankment on the north side of Havana Pond near the center of Section 11 (Figure 3.2-1) in the Irondale Gulch Drainage Basin. The pond stores surface and storm runoff from the Havana and Peoria Interceptors. The station consists of a Stevens Type F recorder, a potentiometer, and a DP115 datapod housed in a protective cover that is mounted on a vertical stilling well. A Style C staff gage is mounted to a vertical post on the walkway leading to the stilling well. The stilling well is positioned near Havana Pond's low stage waterline and is hydraulically connected to the pond. This station was used historically to monitor storage at the pond. The existing outflow structure is made of an 18-in. diameter culvert with a gate that is kept shut except during extremely high pond stages. A spillway was constructed in October 1988 to accept pond water when the water exceeds 7.9 ft on the staff gage. The downstream end of the culvert and spillway discharges into a poorly defined channel before entering Sand Creek Lateral about 25 ft away.

Maintenance requirements at the station consist of monthly changing of the data storage module and batteries in the datapod. Water levels in the pond drop below the stilling well and staff gage during drier times of the year. To eliminate the problem, a trench is excavated to hydraulically connect the pond with

the stilling well and staff gage. The stilling well also accumulates sediment which must be periodically removed to keep the float of the Stevens Type F recorder in water.

3.2.1.1.4 Ladora Weir (SW02001)

The Ladora Weir gaging station is located in the southeast corner of Section 2 (Figure 3.2-1) in the Irondale Gulch drainage basin. The station monitors flows in the channel complex from Lower Derby Lake to Ladora Lake or Sand Creek Lateral. However, Ladora Weir does not monitor flows from Havana Pond to Sand Creek Lateral. The gaging station consists of a Stevens Type F recorder, a potentiometer, and a DP115 datapod in a protective cover fitted onto a wooden deck. Beneath the deck is a concrete basin that receives flow from Lower Derby Lake. A stilling well and a Style C staff gage are also located in this concrete basin. The section control at the station is a standard suppressed rectangular weir constructed of two 2-in. wide planks fitted on top of the concrete basin wall.

The station's datapod requires monthly changing of the DSM and batteries. This station does not accumulate trash and vegetative debris, but the weir displays leaks through and around the wooden planks.

3.2.1.1.5 South Uvalda (SW12005)

The South Uvalda gaging station is located in an unlined ditch on the southern portion of Uvalda Interceptor in south-central Section 12 (Figure 3.2-1). It monitors surface and storm sewer waters originating from off-post residential and industrial properties flowing onto RMA and the Irondale Gulch drainage basin. Streamflow is directed to either of the Derby Lakes. A CR-10 data logger along with a nitrogen tank for the bubbler system was installed during April 1989 inside a wooden storage shed. The Stevens Type F recorder is enclosed in a steel protective cover on top of a steel-cased stilling well that is hydraulically connected to the active stream channel with 2-in. intake pipes. The Stevens recorder is run in conjunction with the data logger to provide two records of stage for comparison. The compound control structure located at the station consists of a V-notch in a 12-in. wide concrete weir. A Style C staff gage is located in the active channel near the intake pipes.

This station requires periodic maintenance. The nitrogen tank for the CR-10 bubbler is replaced with a fully charged cylinder when the tank pressure drops below 200 psi on the regulator gage. The data logger's RAM-pack storage module is changed every month or data in the storage module is downloaded to a PC-compatible computer. The battery for the CR-10 is changed whenever the voltage drops to less than 12 volts. The station accumulates brush and trash, and the stream banks are nearly overgrown with vegetation. The brush and trash are removed as needed, and the overgrowth is removed annually by

Army personnel. The station's stilling well also requires periodic flushing because the intake pipes fill with silt.

3.2.1.1.6 North Uvalda (SW01001)

The North Uvalda gaging station is actually located on the original Highline Lateral ditch in the southeast corner of Section 1 in the Irondale Gulch drainage basin, about 1,500 ft upstream of the inlet to Lower Derby Lake (Figure 3.2-1). It is positioned to monitor surface water delivered to Lower Derby Lake. This surface water originates from an area south of RMA, either from Highline Lateral or from Uvalda Interceptor canal. The station consists of a Stevens Type F recorder in conjunction with a potentiometer, and a DP115 datapod housed in a protective box that is mounted on a corrugated metal pipe stilling well. The stilling well is adjacent to the active stream channel and is hydraulically connected to the stream with 2-in. intake pipes. A Style C staff gage is in the active channel at the stilling well's intake pipes. The compound control structure located at the station is a broad-crested concrete weir.

The station requires normal maintenance, such as removing brush and trash, and flushing the stilling well intake pipes. The staff gage at this station was lowered to the ditch bottom in July 1989. Additionally, the data storage module and batteries in the datapod are changed monthly.

3.2.1.1.7 Highline Lateral (SW12007)

The Highline Lateral gaging station is located on the Highline Lateral, 20 ft south of Sixth Avenue in the northeast corner of Section 12 (Figure 3.2-1) in Irondale Gulch drainage basin. The station number was changed in 1989 from SW07003 to reflect its actual section. It is situated along the unlined Highline Lateral irrigation ditch, which delivers Army-owned shares of irrigation water from the South Platte River to the Derby Lakes. The station is equipped with a Stevens Type F recorder in a protective cover mounted on an open-ended wooden-cased feeder channel. The wooden feeder channel is about 10 ft upstream from the control and is hydraulically connected to the main channel. This station was equipped with a DP115 datapod from June 22 to July 6 of WY89. The section control for the station is a Cipolletti weir.

The station does not collect excessive amounts of trash and vegetative debris. Eventually, a new stilling well could be needed to replace the wooden feeder channel box. The stage record exhibits a broad trace rather than a clearly defined water level because the feeder box permits rippling water. A new stilling well would correct this problem. The old standard staff gage at this station was replaced on August 10 of FY89 with a Style C staff gage. The new staff gage was installed opposite the feeder canal to directly effect the float on the Stevens recorder.

3.2.1.1.8 South Plants Ditch (SW01003)

The South Plants Ditch gaging station is located near the center of Section 1 in the Irondale Gulch drainage basin (Figure 3.2-1) at a diversion structure that monitors flow originating from the South Plants area. The station consists of a Stevens Type F recorder in a protective box mounted on a corrugated metal pipe stilling well that is hydraulically connected to the ditch with two 2-in. intake pipes. A Style C staff gage is positioned in the active ditch. The compound control structures located at the station are sharp-crested, 90° V-notch weirs. These are mounted on wooden planks attached to the outflow sides of the diversion structure. Flow can simultaneously pass over the weirs at the upper and lower ends of Derby Lake. This station did not require maintenance during WY88 and WY89 because flow is very infrequent.

3.2.1.1.9 South Plants Lake Monitoring Stations

Staff gages that monitor lake levels are located at observation points on each of the lake dams. The lakes currently being monitored (Upper Derby, Lower Derby, Ladora, and Mary) are all within the Irondale Gulch drainage basin. Figure 3.2-1 shows the location of each lake observation point.

The Upper Derby Lake staff gage is located on the west shore of the lake near the outflow to Lower Derby Lake. The station number is SW01004. This staff gage is calibrated in 0.1 ft increments and has a range of 0 to 10.0 ft. The lake will overflow its banks at a staff gage of about 9.0 ft. The elevation of the zero reference point was 5,247.77 ft-mean sea level (ft-msl) on January 20, 1989.

The Lower Derby Lake staff gage is located on the west end of the lake near its outfall to Ladora Weir. The station number is SW01005. The staff gage is divided into increments of 0.1 ft and has a range of 3.0 to 21.0 ft. This lake overflows at a gage reading of 21.2 ft. The zero reference elevation was 5,230.17 ft-msl on February 22, 1989.

The Ladora Lake staff gage is located on the west end of the lake near pump station SW02003. A new staff gage installed in September 1989 has a precision of 0.1 ft and spans a vertical distance from 0 to 13.0 ft. Overflow occurs at 12.4 ft. The zero reference elevation of the staff gage, 5,207.11 ft-msl, was taken on October 11, 1989.

Water elevation at Lake Mary is monitored by staff gage SW02004, located on the west end of the lake. A Style C staff gage with a precision of 0.01 ft and a range from 0 to 2.00 ft is used to monitor the lake levels. Overflow of the Lake Mary dam occurs at 1.34 ft. The zero reference elevation is 5,202.39 ft-msl, as determined on January 20, 1989.

3.2.1.2 First Creek Drainage Basin

The First Creek drainage basin is located predominantly on the eastern half of RMA, and is bordered by the Second Creek drainage basin to the northeast, the South Platte drainage basin at the Basin A drainage basin, and the Irondale Gulch drainage basin to the west and southwest (Figure 1.4-1). The primary source of streamflow in First Creek drainage basin is First Creek, but the drainage can also receive streamflow from Upper Derby Lake Overflow, Sand Creek Lateral, Highline Canal and the Sewage Treatment Plant (Figure 1.4-1). Surface water that exits RMA in the First Creek drainage basin is confined to First Creek where it flows off post along the northern border.

The four monitoring stations located within the First Creek drainage basin are South First Creek (SW08003), North First Creek (SW24002), First Creek Off-Post (SW37001), and the Sewage Treatment Plant (SW24001). The status of monitoring equipment used at these stations as of the end of FY89 is listed in Table 3.2-2.

3.2.1.2.1 South First Creek (SW08003)

With the construction of a retention pond immediately upstream of the South First Creek station, located in Section 5, and the subsequent rerouting of First Creek, the flow bypassed this station at the end of September 1988. A new station was constructed upstream of the retention pond on First Creek in Section 8. The new South First Creek monitoring station is located in the northeast quarter of Section 8 (Figure 3.2-1) and is used to monitor flow coming into the First Creek drainage basin on RMA. A new concrete V-notch weir was constructed in this area in a narrow reach of channel in October 1988. The station is equipped with a Stevens Type F recorder housed in a protective box and is mounted to a corrugated metal pipe stilling well that is hydraulically connected to the active stream with two 2-in. intake pipes. During April 1989 the station was also equipped with a CR-10 data logger/bubbler system, which is housed with a nitrogen supply tank inside a wooden storage shed. After April 1989, the Stevens recorder was used to provide a visual stage record and a data backup of the CR-10 data logger/bubbler system. The Style C staff gage is located in the active stream channel. The compound control structure located at the station is a concrete V-notch weir.

Minimal maintenance is required at this station. The nitrogen tank for the CR-10 bubbler system is replaced when tank pressure drops below 200 psi, and the CR-10 battery is replaced when voltage drops below 12 volts. The RAM-pack storage module on the data logger is changed monthly; data can also be downloaded directly to a PC-compatible computer.

3.2.1.2.2 North First Creek (SW24002)

The North First Creek monitoring station is located in the northeast quarter of Section 24 in the First Creek drainage basin (Figure 3.2-1). This station monitors surface-water flows that leave RMA on First Creek. Installation of the station was completed in March 1989. The station is equipped with a Stevens Type F recorder housed in a protective box and is mounted to a corrugated metal pipe stilling well that is hydraulically connected to the stream channel with two 2-in. intake pipes. A CR-10 data-in. logger/bubbler system was installed during April 1989 in a wooden storage shed with a nitrogen supply tank. A Style C staff gage is positioned in the active stream channel opposite the stilling well's intake pipes. The compound control structure at the station is a concrete V-notch weir constructed in October 1988.

Minimal maintenance is required at this station. The nitrogen supply tank for the CR-10 bubbler system is replaced when tank pressure drops below 200 psi, and the CR-10 battery is changed when the charge drops below 12 volts. The RAM-pack storage module on the data logger is changed monthly; data can also be downloaded directly to an IBM-compatible personal computer. Removal of brush is sometimes required following high winds.

3.2.1.2.3 First Creek Off-Post (SW37001)

The First Creek Off-Post monitoring station is located about one-half mile north of RMA's northern boundary and directly southeast of Highway 2 (Figure 3.2-1) in the First Creek drainage basin. This station is used to monitor surface-water flow between the North First Creek station and this station. The First Creek Off-Post station did not record stage data following the winter of 1988 because water was flowing beneath the H-flume and recording system. The station was determined to be nonreparable and was redesigned and replaced in June 1989. The replacement included a concrete triangular-throated flume. Stage data collection began in July 1989. The gaging house was originally equipped with a Stevens Type F recorder, DP115 datapod, and Style C staff gage, but vandalism during August 1989 interrupted the station's record keeping for the remainder of WY89. The gaging house also serves as the stilling well, and is hydraulically connected to the concrete flume by a 2-in. intake pipe.

3.2.1.2.4 Sewage Treatment Plant (SW24001)

A totalizing flow meter records flow from the Sewage Treatment Plant in Section 24 in the First Creek drainage basin (Figure 3.2-1). The Sewage Treatment Plant processes on-post sanitary sewer effluents and discharges treated water to a lined ditch that becomes unlined as it enters First Creek. The flow meter readings in hundreds of gallons were converted into gallons per day, gallons per week, and gallons per month. The meter is inside the building adjacent to the outfall. The meter is read daily by Army personnel, and flow is monitored weekly by CMP surface-water personnel.

3.2.1.3 South Platte Drainage Basin

The South Platte drainage basin is located in the northwestern half of RMA, and is bordered by the First Creek drainage basin to the east and the Irondale Gulch drainage basin to the southwest (Figure 1.4-1). The Basin A Subdrainage Basin and a portion of the Sand Creek Lateral Subdrainage Basin is located in the South Platte drainage basin (Figure 1.4-1). Streamflow in the South Platte drainage basin originates from the Basin A inflow and terminates in the Basin A lime pond. No defined stream channel exits RMA within the South Platte drainage basin. The Sand Creek Lateral channel within the Sand Creek Lateral Subdrainage Basin enters into the First Creek drainage basin near the northern border of the North Plants; however, flow in this channel is extremely rare (Figure 1.4-1).

The Basin A gaging station (SW36001) was the only surface-water monitoring station located in the South Platte drainage basin as of the end of FY89 (Figure 3.2-1). Equipment in use at the station is listed in Table 3.2-2.

3.2.1.3.1 Basin A (SW36001)

The Basin A gaging station, located in a drainage ditch in the southwest corner of Section 36 (Figure 3.2-1), monitors storm sewer runoff from the South Plants area into the ditch. Surface waters flow past the structure into a concrete-lined channel that flows into the Basin A pond. The station consists of a Stevens Type F recorder in conjunction with a potentiometer and DP115 datapod in a protective box mounted on a corrugated metal pipe stilling well in the center of the ditch. The section control structure located at the station is a steel 90° V-notch weir. A Style C staff gage is attached to the weir.

Maintenance at the station consists of monthly changing of the data storage module and the batteries in the datapod. Brush is removed periodically from the upstream and downstream sides of the weir.

3.2.2 SURFACE-WATER QUANTITY DATA ACQUISITION

The procedures and methods used to obtain and calculate surface-water quantity data for the CMP are discussed in this section. The discussion includes procedures and methods that were used to reduce the strip charts to a digital format, obtain data from datapods and data loggers, obtain instantaneous discharge measurements, and develop rating curves for each station. The rating curves for each station are used to convert the continuous stage data to daily discharge records for each station. This conversion and the validation of this data are also outlined in this section. The streamflow data collected during WY88 and WY89 were for stage and instantaneous discharge. Data were collected for stage with staff gages and continuous water level recorders, and for instantaneous discharge with flow meters, weirs or flumes. Instantaneous discharge measurements are used to construct rating curves. Gage height information is

used with rating curves to create a gage height/discharge relationship and to generate daily discharge records. Discharge measurement and rating curve development procedures are described in Sections 3.2.2.5 and 3.2.2.6, respectively.

3.2.2.1 Strip Chart Procedures and Equipment

The continuous monitoring stations were visited weekly to change strip charts and record staff gage measurements. Continuous water-level information was recorded on Stevens Type F recorders, each attached to a float, beaded wire and pulley. The Stevens recorders are located at monitoring stations described in Table 3.2-2. During WY88 and WY89, the Stevens recorders collected stage data in analog format. (During WY89 analog data were collected with either data loggers or datapods that collected data in a digital format.) Weekly activities at each recording station included collecting and replacing strip charts; checking recorder operation; calibrating strip charts to the outside observed stage and initial time; removing obstructions from stilling wells, channel sections and control structures; and checking the digital recorders. Each strip chart produced during WY88 and WY89 was reviewed for completeness and accuracy.

The review included the following steps:

- general check on station-by-station consistency with discharge information;
- station-by-station review of outside gage height settings to ensure consistency and agreement with strip chart information and data logger information;
- review and comparison of datapod data with strip chart information;
- review of applied pen correction on a station-by-station basis; and
- correction and substantiation of observed stage information.

Due to freezing conditions, the Stevens recorders were not used at most stations between December and March during WY88 and WY89.

3.2.2.2 Datapod Procedures and Equipment

Five surface-water monitoring stations at RMA (North Uvalda, Ladora Weir, Peoria Interceptor, Havana Pond, and Basin A) were equipped with Omnidata International DP115 datapod digital recorders during FY89 (Table 3.2-2). The DP115 datapod is a battery-operated, single channel, stream stage recorder. The datapod is coupled to a Stevens Type F recorder with a 10-turn potentiometer. The potentiometer

receives electrical current from the datapod's power source. Movement of the recorder's pulley system varies the resistance of the potentiometer, and is recorded as a change in potential by the datapod. These changes in potential correlate to changes in stream stage.

The data provides a means of cross-checking the stage data of the recorder strip chart for continuity, and developing a digital stage record. The stage record from either the datapods or the digitized strip chart records is then used in conjunction with the established rating curves to produce daily discharge records.

The DP115 automatically records the date, time, and corresponding gage height on a nonvolatile solid-state memory data-storage module (DSM). The DSM can store at least one month of stage data. Detailed specifications and operating procedures are in Appendix A-6.2 of the FY89 SWDAR (RLSA).

The continuous monitoring stations equipped with DP115 datapods were visited weekly to obtain instrument status readouts (short dumps). Data storage modules and batteries were changed at approximately one-month intervals.

3.2.2.3 Data Logger Procedures and Equipment

Four RMA surface-water stations (North First Creek, South First Creek, South Uvalda and Havana Interceptor) were equipped with Campbell Scientific CR-10 data loggers and bubbler systems during FY89 (Table 3.2-2). These stations were chosen because they generally exhibit year-round flow. At times, including WY88, collection of stage data during the freezing months when some high snowmelt flows occur has been difficult because the float and pulley system used with the Stevens recorders freezes inside the stilling wells. The CR-10 data logger/bubbler system was the primary source of initial stream stage data; however, strip chart data are used to fill gaps in the data logger's record when necessary during nonfreezing months, and to provide a visual record. The stage information is then used in conjunction with the established rating curves to produce daily discharge records.

The CR-10 data logger/bubbler system is a multiple-channel recording instrument that can handle both analog and digital input. The bubbler system consists of a tube and orifice through which nitrogen is fed. The pressure in the tube required to force the nitrogen through the orifice corresponds to the hydrostatic head of the water over the orifice. A transducer senses the pressure in the bubbler tube. The system calibrates itself based on two pressure measurements at a known distance apart in a reference cylinder located in the gage house. These measurements are used to correct the measured pressure value of the CR-10 bubbler line in the stream. The data logger records all information at 15-minute intervals on a 720K RAM-pack storage module. The information includes temperature, stage data, calibration data and battery voltage.

Weekly activities at the four monitoring stations equipped with the data loggers included reading staff gage water levels, measuring water depths over bubbler lines, recording instrument status readouts, and checking the nitrogen supply tanks of the bubbler systems. Other periodic maintenance involved monthly changing of the RAM-pack storage modules, and changing of the nitrogen cylinder and battery as needed. Detailed specifications and operational procedures for the CR-10 data logger/bubbler system are located in Appendix A-6.3 of the FY89 SWDAR (RLSA).

3.2.2.4 Stream Stage Data Computation

The strip chart analog stage data collected during FY88 and FY89 were reduced to a digitized format using the computer program CPSPC (Radian Corp., October 1987, Version 3.1) in conjunction with a digitizer. Surface-water flow data originally exist in analog form as a time-versus-gage height line chart, where the x-axis represents the time in hours and the y-axis represents the staff gage reading taken on a continuous basis. The digitizing process converts this data from analog to digital form. The digitizing tablet registers digitized points in inches, using the lower left corner of the tablet as an origin point (0", 0"). After the graph has been taped to the digitizing tablet, three reference points (upper left, upper right and lower left) are digitized. Using the keyboard, the user then assigns a graph scale coordinate to define the graph location of each reference point. In this case, the scale was correlated to Julian date and scientific hours for time and to 0.01 ft for gage height.

As the user digitizes points along the line graph, the points are stored in a computer file in digitizing inches. After the line has been digitized, the software converts the digital file into units used by the line chart graph. The conversion is based on a scale calculated from the data associated with the three reference points. For example, starting at the upper left and upper right reference points, it might be calculated that 1 inch along the x-axis represents 24 hours. Therefore, a difference of one between the x-coordinate values of two points means that 24 hours passed between these two readings.

This method reduced the strip charts to digitized output that was used to calculate stage-discharge relationships. The minimal digitized strip chart points chosen were 0.00, 6.00, 12.00, 18.00 and 24.00 hours for each record day. Other significant stage points selected for digitization were high flow events, when gage heights were digitized at a minimum of 15-minute intervals, and any stage points that exhibited 0.1+ ft of deflection within any 2-hour period. Finally, the digitized stage output was compared to the strip chart analog record and corrected to the observed staff gage settings. Problems noted in this process included insufficient recoding of digitized points to characterize the gage height record, particularly during high flows, and incorrect pen adjustments. For periods of no record (when equipment may have malfunctioned), the gaps were filled in by estimating the stage or supplementing with datapod or data logger data. This estimated part of the record was extrapolated from the week's beginning and ending staff gage readings. The estimated values are noted in the remarks section of the water-discharge record in Appendix A-8.1 of the FY88 and FY89 SWDAR (RLSA, 1990a and 1990b).

Datapod records were collected primarily to assess the feasibility of using the datapods and developing procedures for future datapod collection. The digital data logger stage record is downloaded from the RAM-pack storage module to a computer. The data logger stage data were used primarily and supplemented with Stevens recorder stage data when data gaps occurred in the digital record. Details of the stage data process are in Appendix A-6 of the FY89 SWDAR (RLSA).

3.2.2.5 Discharge Measurement Procedures and Computation of Discharge Data

Discharge is defined as volume per unit time and is expressed throughout this report in cubic feet per second (cfs). Discharge measurements were made monthly at stations where flow was displayed, with additional measurements made at high surface-water flow and during spring and fall sampling. In addition to the scheduled monthly measurements, instantaneous discharge measurements were taken whenever unusual flow conditions were observed. Discharge measurements were made using standard USGS streamflow measurement techniques (Rantz, 1982). Low to moderate flow measurements were made with a Teledyne-Gurley Pygmy current meter, a Marsh-McBirney Model 201 current meter with top-setting wading rod, or 100 mm and 200 mm long-throated flumes (Appendix A-2.2, RLSA, 1990b). Higher flows were measured with a Price Type-AA current meter with top-setting wading rod. All meter measurements were wading measurements, i.e., the hydrographer waded into the stream to collect the flow observations. Indirect measurements involved surveying stream channel cross sections and stream slopes using Hydrologic Engineering Center (HEC-2) computer analysis (U.S. Army Corps of Engineers, 1982). This analysis was used to extend the upper and lower limits of the rating curves.

Each measurement was taken at the most desirable stream cross section monitoring station. The stream cross sections were chosen according to the following criteria:

- a straight reach where flow components parallel each other (laminar flow);
- a stable stream bed, free of large rocks, weeds and protruding obstructions, such as piers and posts, which cause turbulence;
- a flat stream bed profile to eliminate vertical components of velocity; and
- a section having uniform velocity distribution (i.e., avoiding ponded areas), where flow would be similar across the entire section (for meter measurements).

For the shallow streams typically found at RMA, stream depths and flows were generally measured using a top-setting wading rod and a current meter appropriate for the streamflow conditions. When the average depth exceeded 1.5 ft (high flow) the Price Type-AA current meter generally was used. If the average depth of flow was between 1.5 ft and 0.3 ft (low to moderate flows), then a Pygmy current meter

was used. The Marsh-McBirney current meter was used as a backup to the Type-AA and Pygmy meters. As a safety measure, if the depth of flow multiplied by the velocity exceeded 10 ft^2/sec, wading techniques were not used. A portable, 200 mm long-throated flume was put into use during April 1989 and a 100 mm long-throated flume was put into use in June 1989. Discharges ranging from 0.0078 cfs to 0.3099 cfs are obtainable with the 100 mm flume and discharges of 0.0367 cfs to 1.762 cfs are measurable with the 200 mm flume.

The calibration of each meter was checked before the start of the current meter measurements at each site. The calibration checks for the Pygmy and Type-AA current meters (which both have a vertical shaft and rotating cups), are detailed in Appendix A-2.2 of the FY89 SWDAR (RLSA, 1990b). Field procedures implemented to measure and calculate current meter instantaneous discharge are detailed in Appendix A-2.2 (RLSA, 1990b). The procedures used to measure discharge rates with the portable flumes are also detailed in Appendix A-2.2 (RLSA, 1990b).

3.2.2.6 Rating Curve Development Procedures

Continuous records of discharge at the RMA gaging stations are computed by assigning a discharge rating for each stream location to records of stage. Discharge ratings for the RMA stations are typically curves plotted on logarithmic paper that relate stage to discharge (Appendix A-3.2 and A-3.3; RLSA, 1990b). These curves are also described by rating equations (Appendix A-4; RLSA, 1990b). The stage-discharge relationships (rating curves) for the new RMA gaging stations, or existing stations with modified control structures, were determined empirically by periodic measurements of discharge and stage. This information was evaluated with a theoretical analysis using information on channel geometry (Appendix A-1; RLSA, 1990b). The discharge measurements were usually made with a current meter or portable structure, as described in the previous section. For ranges in stage where empirical measurements were not available, theoretical stage-discharge relationships were computer-generated using measurements of cross section and reach geometry (HEC-2 analysis). The new gaging stations, or stations with a modified section control that required development of a stage-discharge relationship during FY89 included:

- Peoria Interceptor (SW11001) — modified control structure
- South First Creek (SW08003) — new station
- North First Creek (SW24002) — new station
- First Creek Off-Post (SW37001) — new control structure

For gaging stations with previously defined rating relationships, periodic measurements of discharge and stage were used to confirm the permanence of the rating and/or to follow changes (shifts) in the rating.

Shifts in the discharge rating reflect the variability of stage-discharge relationships, either gradual or abrupt, because of changes in the physical features that form the control for the station.

Following the review, verification and validation of instantaneous discharge measurements, valid measurements were plotted to determine if the rating for the previous water year was applicable for part or all of the current water year. This information is summarized in Appendix A-6 of FY88 SWDAR (RLSA, 1990a) and in Appendix A-5 of the FY89 SWDAR (RLSA, 1990b). Discharges computed from the previous rating were compared to current water year instantaneous discharges. Percentage differences between measured and computed discharges were calculated. As long as changes were random in sign and within ± 5 percent, the previous rating was used to convert WY89 continuous stage data to discharge (Rantz, 1982). For low-flow measurements, the ± 5 percent criteria is sometimes too stringent because of station control insensitivity; therefore, stage departures were calculated for low flow measurements using the same methodology as used to calculate discharge departures. If the indicated departures in stage did not exceed ± 0.02 feet, the previous rating was kept in effect (Rantz, 1982). Instantaneous discharge data from the first year of the CMP (FY88) were used with historic stage-discharge measurements, cross-sectioned survey data and historical setup chart data to: 1) evaluate and verify, if possible, the historical rating relationships, or 2) modify and update relationships as appropriate. The gaging stations on the RMA that required confirmation and/or shifts to define stage-discharge relationships during FY89 included:

- Havana Interceptor (SW11002)
- Ladora Weir (SW02001)
- South Uvalda (SW12005)
- North Uvalda (SW01001)
- Highline Lateral (SW12007)
- South Plants Ditch (SW01003)
- Basin A (SW36001)

The relationship of stage to discharge is usually controlled by a section or reach of channel known as a station control that is located immediately downstream from a gage. Station controls at RMA are classified as channel control, section control or compound control. Channel control exists when the physical features of a long reach of channel control the stage-discharge relationship. Section control can be artificial or natural, but must have physical features such as a weir, flume or rock ledge outcrop within

a single cross section that maintains a stable relationship between stage and discharge. A compound control is a situation in which no single control is effective for the entire range of experienced stages. Compound controls typically exhibit section control at lower stages, and channel control at medium to high stages as section control features become submerged (Rantz, 1982).

The types of station control at RMA gaging stations are:

- Channel Control
  - Havana Interceptor - concrete-lined channel

- Section Control
  - Highline Lateral - Cipolletti weir
  - Ladora Weir - standard suppressed rectangular weir
  - Basin A - 90° V-notch weir
  - First Creek Off-Post - concrete triangular-throated flume
  - South Plants Ditch - 90° V-notch weir
  - South First Creek - concrete V-notch weir
  - North First Creek - concrete V-notch weir

- Compound Control
  - South Uvalda - compound V-notch weir
  - North Uvalda - compound V-notch weir
  - Peoria Interceptor - compound weir with a 90° V-notch and standard contracted rectangular weir

The methodology used to determine the stage-discharge relationship for each of the gaging stations on the RMA during the first two years at the CMP is presented in Appendix A-8.1 of the FY88 Surface-Water Report (RLSA, 1990a) and in Appendix A-3.1 of the FY89 Surface-Water Report (RLSA, 1990b).

3.2.2.6.1 Conversion of Stream Stage to Discharge

A computer program was used to convert gage height data to instantaneous and daily average discharges, and to produce formatted monthly summaries of the discharge records. The program steps are as follows:

- Check the time and date of each gage height value to select the rating equations, shifts, and/or adjustments corresponding to the respective time period. Compare the magnitude of each gage height value to the valid range of each rating equation to select the appropriate equation.

- Use the software to compute a discharge for each of the gage height values occurring on a given day using the selected rating equations of the general forms.

- Each daily discharge data set is time-weighted and summed to obtain the daily average using the formula:

$$Q_a = \frac{1}{24} \sum_{i=1}^{n} \frac{(t_i + 1) - (t_i - 1)}{2} Q_i$$

where

Q_a = average daily discharge (cfs);

n = number of gage height entries for a given day;

t_i = 24-hour time in hours corresponding to gage height entry i; and

Q_i = discharge corresponding to gage height entry i (cfs).

This process is repeated for each day in the record.

- Finally, the monthly totals and averages are calculated from the daily averages, and the results are formatted for printing.

3.2.2.6.2 Channel Reach Surveys

During the first 2 years of the surface-water CMP, channel cross section surveys were conducted at the RMA gaging stations that did not have laboratory-rated structures. This provided section control for the complete range of stages being monitored. Channel cross-section surveys were made at the North First Creek gaging station (SW24002) to support a theoretical high-flow extrapolation of the stage-discharge rating relationship during WY89. Five cross sections were surveyed: one channel cross section was surveyed below the concrete structure, one cross section through the center of the concrete structure, and three additional cross sections upstream from the concrete structure.

During WY88 cross section surveys were conducted at four monitoring sites. Six cross sections were surveyed at South Uvalda (SW12005) and at Peoria Interceptor (SW11001). Four were surveyed at North Uvalda (SW01001) and one at Havana Interceptor (SW11002). A detailed description of the procedure used in conducting the channel reach surveys is presented in Appendix A-1.2.4 (RLSA, 1990b). Channel reach survey data are presented in Appendix A-1.2.3 (RLSA, 1990b).

3.2.2.7 Meteorological Data

Warning of major rainfall-runoff events was obtained from a meteorological contractor who forecast storm events on a daily basis for the Stollar team and identified the location of storm activity. This system was used to acquire storm (high-event) sampling and high-flow instantaneous discharge measurements.

Daily precipitation and temperature data for the WY88 and WY89 water years were obtained from the NWS located 2 miles south of RMA at Stapleton Airport. During FY89 weather information was obtained from both NWS and the CMP Air Element. Evaporation data were compiled as a monthly average based on the USACE pan evaporation data collected at Cherry Creek Reservoir.

3.2.2.8 Lake and Pond Stage Data Computations

Physical data on the lakes were collected by weekly monitoring of staff gages. The weekly staff gage readings of the South Plants Lakes and Havana Pond were converted to elevation in feet above mean sea level (ft-msl) and to volume in acre-feet (ac-ft), as determined in a previous study conducted by ESE (Ebasco, 1989; Appendix B). Lake/pond volumes for the surface-water CMP were based on this information and calculated monthly using a refined volume relationship. The stage and elevation relationships determined by previous contractors did not correlate with resurveyed stage/elevation CMP information. For this reason, the elevation-to-volume relationship, rather than the stage-to-volume relationship determined by previous contractors, was used to compute the volumes of the South Plants Lakes and Havana Pond. Havana Pond data were also collected by a Stevens Type F recorder in conjunction with a potentiometer and DP115 datapod. The Havana Pond continuous record was reduced as described in Section 3.2.2.4.

3.2.2.9 Surveying

All water-level monitoring stations and sampling stations were surveyed by Itech, Inc. during WY88 and any changes to the network were resurveyed during WY89. Temporary benchmarks (TBMs) were established at each water level monitoring station. Elevations of staff gages, weirs, TBMs and sample locations were established at each site. Northing and Easting coordinates were surveyed and computed for each of the water-level monitoring stations and sample locations. The information compiled during the first two years of the CMP is in Appendices A-1.1 and B-1 of the FY89 SWDAR (RLSA, 1990b). As noted in Section 3.2.2.8, previously established stage/elevation information for the lakes/pond did not correspond in some instances to stage/elevation survey data collected during the CMP. These differing stage/elevation relationships are shown in Table 3.2-3. Periodic removal of the staff gages on Upper Derby Lake and Ladora Lake for maintenance and repainting may account for the elevation differences reported in the WRI Report and the CMP.

Table 3.2-3 Stage/Elevation Differences Noted Between Data Reported by Previous Contractors and the Surface-Water CMP

	WRI Report (Ebasco, 1989a)		CMP 1988		
	Stage (ft)	Elevation (ft-msl)	Stage (ft)	Elevation (ft-msl)	Difference in Elevation (ft)
Havana Pond	0.00	5,244.20	0.00	5,244.08	0.12
Upper Derby Lake	0.00	5,249.25	0.00	5,247.77	1.48
Lower Derby Lake	0.00	5,231.00	0.00	5,230.17	0.83
Ladora Lake	0.00	5,208.00	0.00	5,207.11	0.89
Lake Mary	0.00	5,202.63	0.00	5,202.39	0.24

3.3 Pre-CMP Surface Water Quality

Surface-water quality data were previously collected at RMA under several programs and tasks. The procedures for sample collection and analysis used by major data-collection programs preceding the CMP surface-water monitoring program are summarized in this section. Surface-water quality samples were collected under the 360 Degree Monitoring Program and Remedial Investigation Tasks 4, 39, and 44. The following sections describe the monitoring networks, strategies, field methods, laboratory analytical methods, and QA/QC procedures used during these programs. This information was gathered from existing documentation, and in some cases supplemented through personal interviews.

3.3.1 Surface Water Quality Monitoring Network

3.3.1.1 360 Degree Monitoring Program

The 360 Degree Monitoring Program was initiated in 1975 primarily to monitor on-post and off-post groundwater quality. Initially, 22 on-post and off-post surface-water locations were sampled for quality. In 1983, 17 surface-water sites were sampled quarterly, and data-collection activities were summarized in periodic data summaries (Ward, 1984). Most data collected under the program from 1979 to 1985 were incorporated into a computer database currently maintained by D.P. Associates (DPA).

3.3.1.2 Remedial Investigation

The RMA Remedial Investigation/Feasibility Study (RI/FS) was initiated in 1984. Sampling formerly conducted under the 360 Degree Monitoring Program was incorporated into several RI tasks. From 1985 to 1987, surface water quality data were collected in conjunction with four RI tasks (Ebasco, et al., 1989a). Twenty-five surface-water sites were sampled under a regional groundwater monitoring program

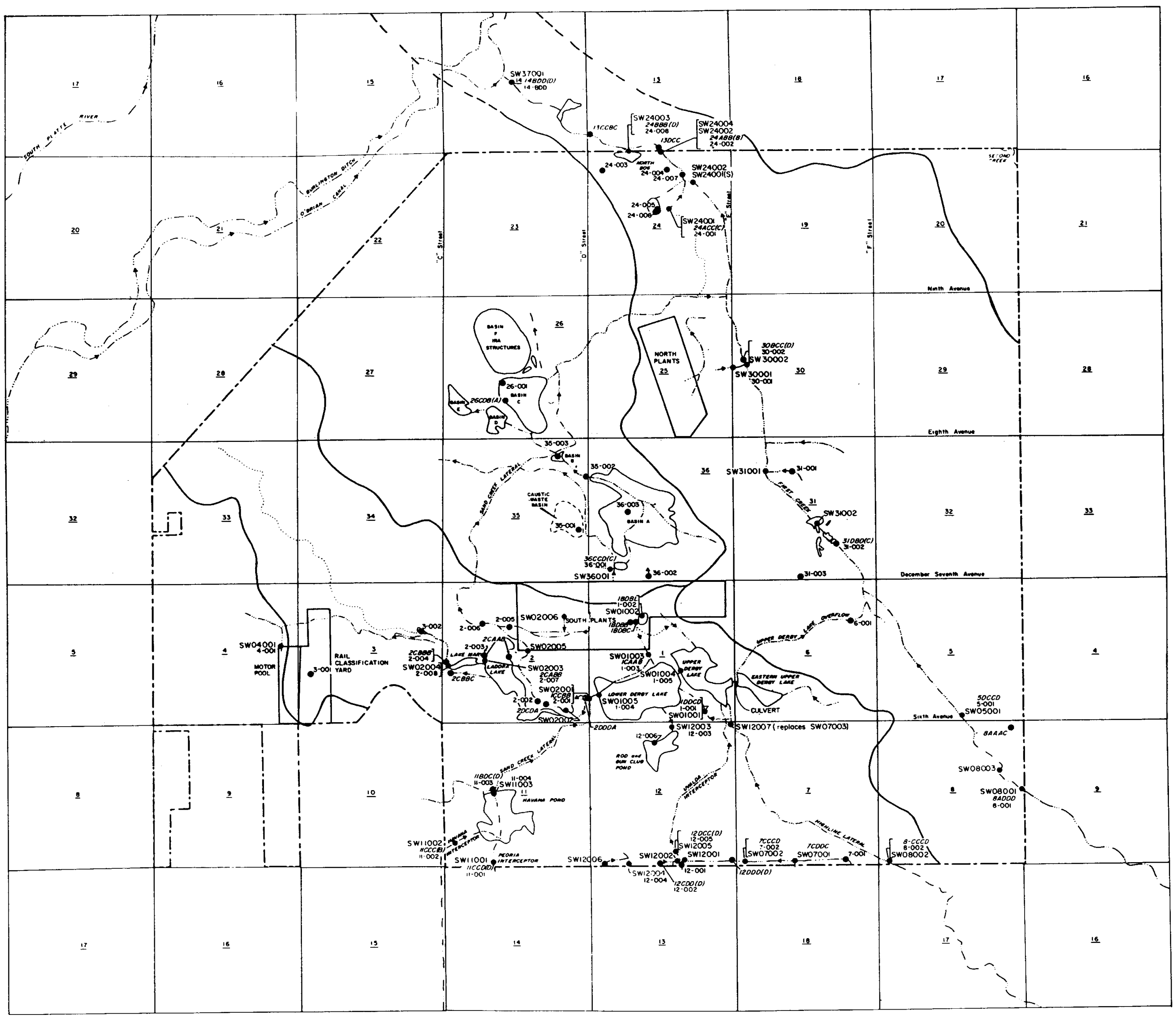
(Task 4) from October 1985 to March 1986 (Ebasco, 1989a). As part of Task 4, sampling for chemical analysis was planned for 29 on-post RMA surface-water locations. During the third quarter of FY86, 19 on-post and 11 off-post surface-water sites were sampled. During the fourth quarter of FY86, 21 on-post and nine off-post surface-water sites were sampled. From December 1986 through September 1987, 11 sites were sampled under Task 39, the off-post RI. Task 39 used the 11 off-post sample locations established by the 360 Degree Program (ESE, 1988e). As part of the Task 44 regional monitoring program, 41 on-post and off-post surface-water sites were sampled from October 1986 to August 1987. Figure 3.3-1 shows the on-post and off-post surface-water sampling locations of the 360 Degree Monitoring Program and Remedial Investigation.

3.3.1.3 Correlation of Previous Networks

As part of the CMP, site data from the historical database and previous reports and documents were reviewed to identify surface-water sampling locations of previous programs. Correlation of historical and current surface-water sampling locations is summarized in Table 3.3-1. Data associated with corresponding historical sampling locations were extracted from the database to form a historical analytical data file for each location. Historical detections at CMP sampling locations are discussed in Section 4.3.1. Historical correlation with previous sampling sites could not be established for some CMP locations; therefore, no historical file was created. In several cases, correlated historical and CMP sampling sites did not correspond exactly. A correlation was made between sites where maps indicated that sampling sites represented measurements from proximal locations exposed to similar environmental conditions. Sampling locations used to construct Table 3.3-1 are shown on Figure 3.3-1. Sampling locations used during the 360 Degree Monitoring Program were derived from historical hand-plotted location maps. The CMP and most of the ESE (Ebasco, 1989a) sampling sites were located using survey coordinates. Sampling sites are shown on Figure 3.3-1.

3.3.2 SURFACE-WATER QUALITY MONITORING STRATEGIES

The Revision I-360 Degree Monitoring Program began in January 1976 with 17 surface-water sites on or adjacent to RMA, and five off-post surface-water sites selected by the Tri-County District Health Department (TCDHD). Water samples from on-post wells were collected monthly by RMA personnel and analyses were performed by RMA and CDH (Ward, personal communication, 1990) for the



Legend

20 Section Number

Lake, Pond or Basin

Stream or Ditch with Flow Direction

Abandoned Stream or Ditch

SW24001 CMP Surface Water Sample Location

24-001 Hunter / ESE Surface Sample Location

24CABB 360° Monitoring Program Sample Location

Arsenal Boundary

Drainage Basin Boundary

N

0 2000 4000
FEET

Prepared for:
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 3.3-1
Correlation of CMP and Historical Surface-Water Quality Sampling Locations

CMP SW FY90H

Table 3.3-1 Correlation of Historical and CMP Surface-Water Sampling Locations (Page 1 of 3)

Section	Sample Location Number: 360° Revisions II & II (1979-1986)	Tasks 4,39,44 ESE (1985-1987)	CMP (1988-1989)
Section 1	IDDCD	1-001	SW01002
	IBDBL	1-002	SW01002
	ICAAB	1-003	SW01003
	N	1-005	SW01004
	N	1-004	SW01005
	IBDBB	N	N
	IBDBC	N	N
Section 2	ICCBB	2-001	SW02001
	2DCDA	2-002	SW02002
	2CABB	2007	SW02003
	N	2-008	SW02004
	N	N	SW02005
	N	N	SW02006
	N	2-003	N
	2CBBB	2-004	N
	N	2-005	N
	N	2-006	N
	2CBBC	N	N
	2DDDA	N	N
	2CAAB	N	N
Section 3	N	3-001	N
	N	3-002	N
Section 4	N	4-001	SW04001
Section 5	5DCCD	5-001	SW05001
Section 6	N	6-001	N
Section 7	7CDDC	N	SW07001
	7CCCD	7-002	SW07002
	N	7-001	N
Section 8	8ADDD	8-001	SW08001
	8CCCD	8-0002	SW08002
	N	N	SW08003
	8AAAC	N	N
Section 11	11CCD(D)	11-001	SW11001
	11CCC(B)	11-002	SW11002
	N	11-004	SW11003
	11BDC(D)	11-003	N

Source: RLSA, 1990b
N - Denotes no correlative sampling location

Table 3.3-1 Correlation of Historical and CMP Surface-Water Sampling Locations (Page 2 of 3)

Section	Sample Location Number: 360° Revisions II & II (1979-1986)	Tasks 4,39,44 ESE (1985-1987)	CMP (1988-1989)
Section 12	N	N	SW12001
	N	N	SW12002
	N	12-003	SW12003
	N	12-004	SW12004
	12DCC(D)	12-005	SW12005
	N	N	SW12006
	N	N	SW12007 (replaces SW07003)
	12DDD(D)	N	N
	N	12-001	N
	12CDD(D)	12-002	N
	N	12-006	N
Section 13	12CCB(C)	N	N
	13DCC	13DCC	N
Section 14	14BDD(D)	14BDD	SW37001
Section 24	24ACC(C)	24-001	SW24001(F)*
	N	N	SW24001(S)**
	24ABB(B)	24-002	SW24002
	24BBB(D)	24-008	SW24003
	N	N	SW24004
	N	24-003	N
	N	24-004	N
	N	24-005	N
	N	24-006	N
	N	24-007	N
Section 26	26CDB(A)	26-001	N
Section 30	N	300-001	SW3001
	30BCC(C)	30-002	SW3002

Source: RLSA, 1990b
N - Denotes no correlative sampling location
* SW24001(F) - indicates sample collected in Fall 1988
** SW24001(S) - indicates sample collected in Spring 1988
Spring and Fall samples for 24001 were collected at different locations during FY88

Table 3.3-1 Correlation of Historical and CMP Surface-Water Sampling Locations (Page 3 of 3)

Section	Sample Location Number 360° Revisions II & II (1979-1986)	Tasks 4,39,44 ESE (1985-1987)	CMP (1988-1989)
Section 31	N	N	SW31001
	31DBD(C)	31-002	SW31002
	N	31-001	N
	N	31-003	N
Section 35	N	35-001	N
	N	35-002	N
	N	35-003	N
Section 36	36CCD(C)	36-001	SW36001
	N	36-002	N
	N	36-003	N

Source: RLSA, 1990b
N - denotes no correlative sampling location

parameters listed in Table 3.3-2. The off-post surface-water samples were collected quarterly and analyzed by RMA and CDH for the same parameters as on-post sites.

The 360 Degree Monitoring Program was revised in November 1976 using improved quality control (QC) measures (U.S. Army, 1977). This new program, identified as the Revision II-360 Degree Monitoring Program, included 12 surface-water sites on RMA to be sampled and analyzed quarterly by the Army. The off-post surface-water sites sampled by TCDHD, and analyzed by CDH and the Army, remained the same. Analytical parameters for Revision II remained the same as Revision I (Table 3.3-2).

A revised off-post groundwater monitoring program, the Revision III-360 Degree Monitoring Program, was developed in response to a consumptive-use sampling program conducted from December 1984 through January 1985. The consumptive-use sampling results indicated a number of deficiencies in the earlier monitoring programs and the presence of compounds previously not detected during the Revision II-360 Degree Monitoring Program (ESE, 1986a). An expanded suite of analytical parameters was developed to further delineate contaminant distributions (Table 3.3-3).

The Revision III-360 Degree Monitoring Program expanded the network of off-post surface-water sampling stations north of RMA from five to 11 locations to provide a comprehensive assessment of the potential presence of contaminants within the off-post study area. The rationale for selecting the Revision III-360 Degree Monitoring Program sample locations is discussed in Section 5.1 of the ESE Technical Plan (ESE, 1985c).

Based on a review of the surface-water sample locations, and conversations with RMA employees involved with the 360 Degree Monitoring Program, the strategy for the surface-water quality program consisted of quality assessment of the surface water entering, within, and leaving RMA. For example, sample locations along First Creek provide information on the quality of surface water as it enters, passes through, and exits RMA within this drainage basin. Other sample locations, such as Ladora Lake and Derby Lakes, have a history of potential contamination because of their use in chemical plant processes (Ward, personal communication, 1990). Monitoring of irrigation ditches was irregular because of seasonal flow. However, monitoring the quality of surface water entering and exiting RMA in these ditches and other surface-water channels provided information on contamination that may have originated off-post.

Surface-water sampling for RI tasks was part of the overall assessment of the source, nature, and distribution of contamination. The monitoring networks for surface-water sample collection were expanded from the network established by the 360 Degree Monitoring Program to include several more on-post and off-post locations. The Remedial Investigation monitoring strategy continued the goal of assessing surface-water quality and the origins of contaminants detected in the on-post and off-post surface-water channels and impoundments.

Table 3.3-2 Analytical Parameters - Revision I and II 360° Monitoring Porgram

pH
DCPD (Odor Elim)
DIMP
Chlorinated Hydrocarbons (i.e., Aldrin, Dieldrin, Endrin)
Total Hardness
Sodium
Sulfate
Chloride
Conductivity
Nitrate/Nitrite
Dissolved Solids
Chlorate
Fluoride
Phosphonate
Total Phosphonate

Source: Ward, 1984

Table 3.3-3 Analytical Parameters - Revision III 360° Monitoring Program

Aldrin	Chloride
Endrin	Fluoride
Dieldrin	Cadmium*
Isodrin	Chromium*
HCCPD*	Copper*
p,p′ -DDT*	Lead*
p,p′ -DDE*	Zinc*
DBCP	Mercury*
DCPD	Arsenic*
MIBK*	Calcium*
DIMP	Magnesium*
DMMP*	Sodium*
PCPMS	Potassium*
PCPMSO	Nitrate*
$PCPMSO_2$	Nitrite*
Dithiane	Sulfate*
Oxathiane	Alkalinity*
Toluene	Conductivity
Benzene	pH
Xylene (o-, p-)	
Xylene (m-)	
Ethylbenzene*	
Chlorobenzene	
Methylene chloride*	
Chloroform	
Carbon Tetrachloride	
1,2-Dichloroethylene	
Trichloroethylene	
Tetrachloroethylene	
1,1-Dichloroethylene*	
1,1-Dichloroethane*	
1,2-Dichloroethane*	
1,1,1-Trichloroethane*	
1,1,2-Trichloroethane*	

Source: ESE, 1985

* Parameters added after First Quarter sampling

3.3.3 Pre-CMP Surface-Water Quality Monitoring Field Methods

3.3.3.1 360 Degree Monitoring Program

Historical procedures and methods for collection of surface-water samples during Revisions I and II of the 360 Degree Monitoring Program were not documented in sampling plans or task plans. Conversations with RMA employees involved with the 360 Degree Monitoring Program indicate the documentation for sampling programs consisted of an annual sampling schedule defining sample locations with sample dates for each week of the year. The sampling schedules were created jointly by the Army, Shell, and the State of Colorado. (Ward and Anderson, personal communication, 1990).

About 20 groundwater and surface-water samples were collected per week during each quarter of the year (Ward, personal communication, 1990). The sampling locations were identified on a site map and the date and frequency of sampling were defined on the sampling schedule. To maintain continuity, the sampling locations established during the early part of the program were maintained as the program developed. Standard operating procedures for sample collection were not documented until 1983 or 1984 when a Standard Operating Procedures document was written for groundwater sample collection (Ward, personal communication, 1990). However, this document was not found.

Surface-water samples were collected on-post by RMA employees and off-post by TCDHD employees. Grab samples were collected in 1-liter glass jars for Revisions I and II of the 360 Degree Monitoring Program. The jar was rinsed with stream water, then filled, capped, and placed in a cooler for transport to the on-post laboratory (Ward, personal communication, 1990). Samples were transported to the laboratory within 2 to 3 hours of sample collection (Jones, personal communication, 1990). All samples were preserved after arriving at the laboratory. The analyses were completed within the holding time limits (Jones, personal communication, 1990). The sample bottle was filled directly at sample locations where access to surface water was convenient. In areas where access was limited, a dipper was used to rinse and fill the sample bottles. During the first several years of the program, one 1-liter glass bottle which contained sufficient volume for all sample analyses was collected at each sample location. No chain-of-custody (C-O-C) forms were completed for samples during this time (Jones, personal communication, 1990). In 1981 or 1982 the containers were changed and samples for organic analysis were collected in glass jars and samples for inorganic analysis were collected in plastic bottles. At this time field measurements for recording the pH, temperature, and specific conductance were initiated (Ward, personal communication, 1990).

Procedures for surface-water sample collection for the Revision III-360 Degree Monitoring Program are documented in the RMA Off-Post Assessment, Contamination Assessment Report (ESE, 1987c). Surface-water samples were collected by entering the stream and wading upstream to the sample location. The containers were filled directly as grab samples by holding the container just under the water surface at

mid-channel, where possible. The sampling procedure was modified as necessary for stations on the South Platte River and during high-flow conditions on other streams or channels when it was impractical to wade to mid-channel. The sampling locations were documented on the surface-water sampling forms (ESE, 1987c,).

3.3.3.2 Remedial Investigation

Surface-water sampling procedures used during Task 4 included: 1) a detailed description of the sample location, stream conditions, and sample appearance; 2) a record of the sample date, sampling time, sample number, and sampler's name; 3) a measurement of in situ water parameters (pH, temperature, and specific conductance); 4) a measurement of stage and discharge in conjunction with sampling at gaging stations, where feasible (ESE, 1985a). Surface-water samples were collected at mid-channel by the surface grab method. Sample bottles were filled directly by holding them just below the water surface with the sampler facing upstream to prevent contamination of the sample by boots or gloves. Samples were collected and decanted from a stainless steel ladle when streamflow was extremely low. Documentation, C-O-C procedures, filtering, preservation, and shipping of samples adhered to USATHAMA Geotechnical Requirements (ESE, 1985a).

Documentation for surface-water sampling procedures used during Task 39 was not available. Surface-water sampling procedures used during Task 44 included: description of the sampling location, sample number, field parameter measurements (pH, temperature, and specific conductivity), analytical requests, and the sampler's name (ESE, 1988b). The sample was collected either directly into the sample container or in a bucket from which the water was decanted into bottles. Samples for organic analysis were collected in amber glass bottles with Teflon-lined caps. Samples for inorganic analysis were collected in polyethylene bottles. A label with the sample number and date was attached to the sample bottle, and the sampler also wrote the sample number and date directly on the bottle. The samples were preserved following USATHAMA geotechnical requirements and stored at 4°C in coolers with ice. C-O-C forms were completed by the sampler and checked by the Field Team Leader. Sample C-O-C forms, packing, and shipping procedures were completed following USATHAMA geotechnical requirements. If samples could not be collected during Task 44 sampling events due to dry or no-flow conditions, sampling was to be performed during periods of major rainfall when streamflow was renewed (ESE, 1988b).

3.3.4 LABORATORY ANALYTICAL METHODS

3.3.4.1 360 Degree Monitoring Program

Surface-water samples collected at RMA were analyzed onpost by the Rocky Mountain Arsenal Analytical Laboratory (RMAL). Analytical methods used by RMAL during the 360 Degree Monitoring Program were based on standard U.S. Environmental Protection Agency (EPA) methods and were certified by and

followed protocol of USATHAMA under the direction of the Installation Restoration Program (Jones, personal communication, 1980). USATHAMA considered the analytes from RMA to be RMA-specific. The analytical methods were specifically selected for analysis of these compounds. RMAL was required to complete a 4-day testing and certification procedure for each analytical method. EPA standard methods were modified when necessary to achieve increased sensitivity for specific RMA analytes. The 4-day testing procedure included evaluation of method precision, accuracy, and reproducibility. Information on USATHAMA-certified methods and the detection limits used by RMAL are not readily available.

TCHD collected surface-water samples off-post and submitted them for analysis to the Colorado Department of Health (CDH) Laboratory. The CDH laboratory was not required to follow USATHAMA protocol or certified methods of analysis (Jones, personal communication, 1980). Documentation regarding the analytical procedures followed by CDH for analysis of surface-water samples for the 360 Degree Monitoring Program are unavailable at this time.

3.3.4.2 Remedial Investigation

Surface-water samples collected during Task 4 were analyzed by ESE Laboratories in both Gainesville, Florida and Denver, Colorado (ESE, 1987b). To obtain lower detection limits and higher accuracy, the analytical methods of Task 4 were quantitatively certified according to USATHAMA methods. The USATHAMA-certified methods were based on standard EPA methods. Semi-quantitative methods were not used in this program. The initial proposed list of 24 target analytes was modified several times and augmented to 50 analytes by the conclusion of Task 4 sampling. Table 3.3-4 presents the list of final target analytes and certified reporting limits (CRLs) for each analyte. The final list of target analytes was generated after reviews of historical information about RMA disposal practices, historical water quality data, and comments by the EPA, Shell Chemical Company, and CDH (ESE, 1987b).

Documentation on analytical reporting limits maintained by DPA indicates analytical procedures conducted during Task 4 included requirements for reporting CRLs. According to USATHAMA, CRLs are used to define a range of analyte concentrations over which a given method can generate analytical results with well-defined accuracy and precision (ESE, 1988e). The lower CRL of a USATHAMA method corresponds to the classical analytical chemistry term of Limit of Quantification (LOQ). It is possible to detect an analyte at concentrations below the lower CRL, but the quantification at these low concentrations is subject to nonreproducible results. Analyte concentrations above the lower CRL have well-defined accuracy and precision values that were used to gauge the significance of the analytical data generated during the RI. For this reason, the use of CRLs rather than "Limits of Detection" were required for the reporting of analytical data.

Surface-water samples collected during Task 39 were analyzed jointly by ESE Laboratories in Gainesville, Florida, and Denver, Colorado (ESE, 1988e). Both laboratories completed a series of USATHAMA

Table 3.3-4 Historical Certified Reporting Limits* (Page 1 of 2)

Analysis/Analytes	Task 4[1] Certified Reporting Limit (μg/l)	Task 39[2] Certified Reporting Limit (μg/l) ESE-G	ESE-D	Task 44**[3] Certified Reporting Limit (μg/l)
Organochlorine Pesticides				
Aldrin	0.07	0.0700	0.0830	0.0830
Endrin	0.05	0.0520	0.0600	0.0600
Dieldrin	0.06	0.0600	0.0540	0.0540
Isodrin	0.06	0.0600	0.0560	0.0560
Hexachlorocyclopentadiene	0.07	0.0700	0.0830	0.0830
p,p'-DDE	0.05	0.0500	0.0460	0.0460
p,p'-DDT	0.07	0.0700	0.0590	0.0590
Chlordane	NA		0.1520	0.1520
Volatile Organohalogens				
Chlorobenzene	0.58	0.58	1.40	1.40
Chloroform	1.4	1.40	1.90	1.90
Carbon tetrachloride	1.40	1.40	1.70	1.70
trans-1,2-Dichloroethylene	2.40	1.20	1.80	1.80
Trichloroethylene	1.20	1.20	1.30	1.30
Tetrachloroethylene	1.10	1.10	1.85	2.80
1,1-Dichloroethylene	1.10	1.10	2.80	1.85
1,1-Dichloroethane	1.20	1.20	1.90	1.90
1,2-Dichloroethane	0.61	0.61	2.10	2.10
1,1,1-Trichloroethane	1.70	1.70	1.10	1.10
1,1,2-Trichloroethane	1.00	1.00	1.63	1.63
Methylene chloride	5.00	5.00	2.50	2.50
Organosulfur Compounds				
P-Chlorophenylmethylsulfone	4.70	4.70	2.24	2.24
P-Chlorophenylmethylsulfoxide	1.30	1.30	1.98	1.98
P-Chlorophenylmethylsulfide	4.20	4.20	1.08	1.08
1,4-Dithiane	1.10	1.10	3.34	3.34
1,4-Oxathiane	2.00	2.00	1.30	1.30
Dimethyldisulfide	1.80	1.80	1.20	1.20
Benzothiozole	NA	2.00	1.20	1.20
Volatile Aromatics				
Toluene	1.21	1.21	2.10	2.10
Benzene	1.34	1.34	1.92	1.92
Xylene (m-)	1.35	1.35	1.04	1.04
Xylene (o,p)	2.47	2.47	1.34	1.34
Ethylbenzene	1.00	1.00	0.62	0.62

Table 3.3-4 Historical Certified Reporting Limits* (Page 2 of 2)

Analysis/Analytes	Task 4[1] Certified Reporting Limit (µg/l)	Task 39[2] Certified Reporting Limit (µg/l) ESE-G	Task 39[2] ESE-D	Task 44**[3] Certified Reporting Limit (µg/l)
DCPD/MIBK				
Dicyclopentadiene	9.31	5.12	9.31	9.31
Methylisobutyl ketone	13.00	5.24	12.9	12.9
DIMP/DMMP				
Diisopropylmethylphosphonate	10.00	10.00	10.1	10.1
Dimethylmethylphosphonate	15.20	15.20	16.3	16.3
DBCP				
Dibromochloropropane	0.13	0.112	0.130	0.130
Metals and Inorganics				
Arsenic	3.90	3.90	2.50	2.50
Mercury	0.20	0.242	0.5	0.5
Calcium	500	500	---	500
Magnesium	500	500	---	500
Sodium	763	764	---	764
Potassium	1,260.00	1,256.00	590.00	590.00
Cadmium	5.2	5.16	---	5.16
Chromium	6.0	5.96	---	5.96
Copper	7.9	7.93	---	7.93
Lead	18.5	18.6	---	18.6
Zinc	20.1	20.1	---	20.1
Chloride	4,800	4,800	1,590	4,800
Fluoride	1,200	1,200	1,000	1,200
Sulfate	10,000	10,000	5,000	10,000
Nitrate/nitrite	10	10.0	---	10.0

Source: 1 ESE, 1987, RIC# 87253R01
2 ESE, 1988, RIC# 89024R01
3 ESE, 1988, RIC# 88063R11

µg/l = micrograms per liter
NA = Not analyzed
ESE-G = ESE-Gainesville, Florida Laboratory
ESE-D = ESE - Denver, Colorado Laboratory

* = Documentation for historical certified reporting limits for samples analyzed during the 360° monitoring program were unavailable for this summary table.

** = Historical certified reporting limits for Task 44 were interpreted from the DPA historical data base, as described in Section 3.3.4.2.

certification procedures designed to ensure accurate and precise determination of the analytes of interest. The laboratories also implemented USATHAMA quality assurance procedures to continuously monitor the quality of these data.

The analytical methods used by the ESE Laboratories during Task 39 were also quantitatively certified by USATHAMA and were based on standard EPA methods. Table 3.3-4 provides the list of analyte CRLs used during this task by the ESE Laboratories in Gainesville and Denver. The final analyte list was generated based on a review of contaminant distribution data from Task 4, and the first quarter results from Task 25 (ESE, 1988e). Data from these tasks were the most recent water-quality data available at project initiation and were used to define which organic and inorganic compounds may be present off-post of RMA (ESE, 1988e).

Surface-water samples collected during Task 44 were analyzed with various USATHAMA-certified techniques to achieve a quantitative determination of water quality (ESE, 1988b). Semi-quantitative confirmation by GC/MS of analytes identified by quantitative techniques, and semi-quantitative identification of nontarget compounds were also conducted. The final analyte list used during Task 44 was adopted from Task 4, with the inclusion of benzothiazole. Table 3.3-4 provides the list of analytes and CRLs used during Task 44. The CRLs for Task 44 were interpreted from the historical CRL database, the known reference methods of Task 44, and the dates of analysis of Task 44 samples. The final target analyte list was based on an evaluation of contaminant source characteristics at RMA and compounds attributable to activities at these sites, a review of the historical chemical compounds detected, and additional input from the Memorandum of Agreement (MOA) parties (ESE, 1988b). Approximately 10 percent of the collected samples were analyzed by GC/MS. The technical quality of the data were assured by proper documentation of procedures used during the Task 44 analytical program.

The historical surface-water CRLs used during Tasks 4, 39 and 44 are listed in Table 3.3-4. A review of the documentation available for the 360 Degree Monitoring Program (revisions I through III) did not produce any record of analytical methods, detection limits, or CRLs employed by this program. The CRLs for Tasks 4 and 39 were available in reports prepared during these investigations. Documentation for Task 44 analytical procedures did not include a list of CRLs. The CRLs for Task 44 were interpreted by using the DPA historical CRL database. This database included information about RMA methods, associated EPA standard methods, certified laboratories, beginning and end dates for certification of specific methods and compounds, and the CRL values. The historical CRL data provides a basis for comparison of analytical data between surface-water quality monitoring programs. Long-term trends in surface-water quality can be evaluated if the data generated over many years is comparable. A review of the CRL data allows assessment of the data comparability for the historical and current surface-water monitoring programs. The comparability of surface-water sampling data generated during the 360 Degree Monitoring Program to that of more recent programs is unknown, since no documentation on CRLs used during the 360 Degree Monitoring Program is available. The CRLs from the RI tasks (Table 3.3-4) can

be compared with the CMP CRLs, listed in Table 3.4-1. The comparability of the data between the historical and recent programs may be assessed, in part, by a review of the CRLs.

3.3.5 QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES

3.3.5.1 360 Degree Monitoring Program

The QA/QC procedures used in this program were not documented in reports. Laboratory personnel involved in the 360 Degree Monitoring Program indicate accuracy and precision of the RMAL analytical methods were tested for each sample lot. No less than five control samples were submitted for analysis with each sample lot (Jones, personal communication, 1980). The control samples were generally standard solutions with known analyte concentrations. Two control samples, essentially one sample with a duplicate, were used to monitor method precision. Three control samples containing known analyte concentrations were used to monitor method accuracy; each sample contained a low, medium, or high concentration of analytes to cover the range of analytical measurement. The control samples were submitted as blind samples and were not distinguished from other investigative samples. Results for the control samples were compared to known concentrations, and to control sample analyses run previously. The QC data were evaluated for adherence to acceptable control ranges. If control ranges were exceeded, the associated investigative samples were rerun or flagged.

Documentation of analytical protocol used during the 360 Degree Monitoring Program is limited. The objective of the laboratory program was to provide quick turnaround of sample analyses (Jones, personal communication, 1980). Generally, samples arrived at the laboratory within about 2-3 hours of sampling. The samples were extracted for organic analyses within 1-2 days and analyses were completed in about 3 to 5 days. The Installation Restoration directive for RMAL was to expedite the sample analysis so the results were available as soon after sampling as possible (Jones, personal communication, 1980). This directive urged reduction of paperwork requirements to enable the quick turnaround time. In response to this directive the sample collection, analysis, and results reporting were not documented under the stringent protocols used since.

3.3.5.2 Remedial Investigation

The QA/QC program implemented during Task 4 of the Remedial Investigation was based on the USATHAMA April 1982 QA program requirements as modified by the U.S. Army Armament, Munitions and Chemical Command Procurement Directorate (ESE, 1987b). This QA/QC program was adopted from the program implemented for Task 1 and was designed to ensure the generation of valid data. The laboratory QA/QC procedures included daily QC of analytical systems, careful calibration to analysis of control samples (spike samples and blank samples), and rigorous documentation of all sample preparation and analysis methods. Requirements for field QA/QC procedures included collection of volatile trip

Table 3.4-1 Data Chem and ESE Laboratories Analytical Methods and Certified Reporting Limits for CMP Water Samples (Page 1 of 3)

Analyte Suite	Parameters	Method Number	Certified Reporting Limits (min.) (μg/l)	(max.) (μg/l)
Volatile Aromatics	Benzene	AV8	1.05	40.2
	Toluene		1.47	39.7
	Chlorobenzene		1.39	39.8
	Ethylbenzene		1.37	39.7
	1,3-Xylene		1.32	39.9
	1,2-Xylene		1.336	39.6
Volatile Halocarbons	1,1-Dichloroethane	N8	0.73	200
	1,1-Dichloroethene		1.70	200
	1,2-Dichloroethane		0.76	200
	Chloroform		0.50	200
	1,2-Dichloroethene		1.10	200
	1,1,1-Trichloroethane		0.760	200
	Carbon tetrachloride		0.990	200
	1,1,2-Trichloroethane		0.780	200
	Tetrachloroethane		0.750	200
	Chlorobenzene		0.750	200
	Methylene chloride		7.40	200
DBCP	1,2-Dibromo-3-chloropropane	AY8	0.195	10
Organosulfur Compounds	Dimethyldisufide	AAA8	0.55	15
	1,4-Oxathiane		2.38	25
	1,4-Dithiane		1.34	25
	Benzothiazole		5.00	50
	p-Chlorophenylmethyl sufide		5.69	50
	p-Chlorophenylmethyl sulfoxide		11.5	75
	p-Chlorophenylmethyl sulfone		7.46	100
Organochlorine Pesticide	Hexachlorocylcopentadiene	KK8	0.048	0.99
	Aldrin		0.050	1.00
	Isodrin		0.051	1.10
	PPDDE		0.054	1.0
	Dieldrin		0.050	1.0
	Endrin		0.050	1.0
	PPDDT		0.049	1.0
	Chlordane		0.095	1.0
Hydrocarbons	Bicycloheptadiene	P8	5.90	104.2
	Dicyclopentadiene		5.00	99.6
	Methylisobutyl ketone		4.90	98.0
Anions	Bromide	HH8A	-	-
	Chloride		716.0	10,000
	Fluoride		80.0	5,000
	Sulfate		250.0	10,000
Nitrate	Nitrate	LL8	10.0	200
Arsenic	Arsenic	CC8	0.1	2.0

Table 3.4-1 Data Chem and ESE Laboratories Analytical Methods and Certified Reporting Limits for CMP Water Samples (Page 2 of 3)

Analyte Suite	Parameters	Method Number	Certified Reporting Limits (min.) (μg/l)	Certified Reporting Limits (max.) (μg/l)
Mercury	Mercury	CC8	0.1	2.0
ICP metals	Cadmium	SS12	6.8	12,5000
	Chromium		16.8	1,000
	Copper		18.8	10,000
	Lead		43.4	10,000
	Zinc		18.0	10,000
	Magnesium		135	100,000
	Calcium		105	100,000
	Sodium		279	100,000
	Potassium		1240	10,000
Volatiles	1,1,1-Trichloroethane	UM21	1.0	100
	1,1,2-Trichloroethane		1.0	100
	1,1-Dichloroethane		1.0	150
	1,1-Dichloroethene		1.0	150
	1,2-Dichloroethane		5.0	150
	1,2-Dichloroethene		1.0	150
	Benzene		1.0	150
	Carbon tetrachloride		1.0	100
	Chlorobenzene		1.0	150
	Chloroform		1.0	150
	Ethyl benzene		1.0	150
	Methylene chloride		1.0	150
	Tetrachloroethene		1.0	150
	Toluene		1.0	150
	Trichloroethane		1.0	150
	1,3-Dimethylbenzene		1.0	150
	Xylene		2.0	300
	Methylisobutyl ketone		1.4	100
Semi-volatiles	Aldrin	UM25	13	300
	Atrazine		5.9	300
	Hexachlorocyclopentadiene		54	300
	Chlordane		37	300
	p-Chlorophenylmethyl sulfide		10	300
	p-Chlorophenylmethyl sulfoxide		5.3	300
	p-Chlorophenylmethyl sulfone		15	300
	Dibromochloropropane		12	300
	Dicyclopentadiene		5.5	300
	Vapona		8.5	300
	Diisopropylmethyl phosphonate		21.0	200
	Dithiane		3.3	100
	Dieldrin		26.0	100
	Dimethylmethyl phosphate		130	200
	Endrin		18	200
	Isodrin		7.8	300

Table 3.4-1 Data Chem and ESE Laboratories Analytical Methods and Certified Reporting Limits for CMP Water Samples (Page 3 of 3)

Analyte Suite	Parameters	Method Number	Certified Reporting Limits (min.) (μg/l)	(max.) (μg/l)
Semi-volatiles (cont.)	Malathion		21.0	300
	Oxathiane		27.0	300
	PPDDE		14.0	300
	PDDT		18.0	100
	Parathion		37	300
Cyanide	Cyanide	TF20	5.0	200
Nitrogen/Phosphate Pesticides	Atrazine	UH11	4.03	100
	Parathion		0.647	50
	Malathion		0.500	50
	Supona		0.787	50
	Vapona		0.500	50

Source: R.L. Stollar and Associates, Inc., 1990b
μg/l = micrograms/liter

blanks, rinse blanks, field blanks, and duplicate samples. Rinse blanks, field blanks, and duplicate samples were collected once each week that investigative samples were collected and submitted. Three volatile trip blanks were required during each week that samples for QC analysis were collected. The specific requirements for laboratory and field quality control followed during Task 4 are described below.

3.3.5.2.1 Laboratory Quality Control

The laboratory QA/QC procedures described below are documented in the Task 1 Technical Plan (ESE, 1985c). Accurate and reproducible results during Task 4 were ensured by daily QC of the analytical systems. Careful calibration and the introduction of control samples (control spikes and blanks) were prerequisites for obtaining accurate and reliable results. Instrument and sample lot controls were described in the Field Laboratory QA Plan (Appendix B) in the Task 1 Technical Plan (ESE, 1985a).

The laboratory coordinator was responsible for monitoring the analytical controls. Failure to meet the standards for instrument calibration or control sample QC represented an out-of-control situation that required immediate corrective action. Written notification of the QC failure was provided to the project manager, and proper corrective action was implemented by the project QA supervisor.

Prior to transmittal of data to USATHAMA, the chemical analysis supervisors and the laboratory QA coordinators were responsible for reviewing and approving analytical data generated for Task 4. Automatic quality control checks were made on the data from each lot of samples processed, using the standardized computerized data management system in each laboratory. In addition, manual QC checks were performed by the chemical analysis supervisor and laboratory QA coordinator in the laboratory.

Each laboratory was required to maintain a chemical data file for each lot of samples analyzed that included (1) copies of logsheets of sample receipt; (2) relevant analysts' notebook pages; (3) extraction logsheets; (4) instrument logsheets; and (5) raw data sheets including complete chromatograms, calibration curve data, calculation worksheets, and final data.

Laboratories were required to maintain control charts for each analysis conducted. The control charts were reviewed by the laboratory QA coordinator and submitted to USATHAMA. Upon generation of a data report in USATHAMA Installation Restoration Data Management Information System (IRDMIS) format for each group of field samples, a portion of the data were validated by the laboratory QA coordinator in each of the laboratories. Validation involved tracking of a final data point through calculations and back to the raw data to verify the reported value and ensure the presence of the required data documentation. All chemical data and results were processed through the USATHAMA Chemical Data Checking Program. Data deficiencies were reported to the chemical analysis supervisors for corrective action.

Appendix B of the Task 1 Technical Plan (ESE, 1985a) documents the reviewing and reporting functions of the project QA supervisor. A formal review and sign-off sheet was required for all analytical results for each completed Army lot of samples. The laboratory QA coordinator was responsible for periodically checking the sign-off sheet to ensure that the review process was complete.

The laboratory QA coordinator was required to submit a QA program status report to USATHAMA upon completion of each lot during the analytical program. This submittal included a hard copy of the lot QC charts. Points that indicated an out-of-control situation were evaluated and explained, and corrective action to prevent recurrence of the situation was described.

3.3.5.2.2 Field Quality Control

The field QA/QC procedures described below are documented in the Task 1 Technical Plan (ESE, 1985a). During Task 4, field sampling QA audits of the surface-water sampling procedures for RMA were conducted by the project QA supervisor or his representative. Samples were required to be collected in properly cleaned containers, preserved promptly and properly, and transported to the laboratory.

Audited field operations included: (1) sample handling, (2) use of sample containers for the specific analysis, (3) use of approved sampling techniques to minimize loss of volatiles, and (4) field documentation and C-O-C practices. The project QA supervisor monitored sample bottle preparation as part of the laboratory audit procedure. Completion of a field sampling audit checklist was required, and a QA Field Audit Report was submitted to the project manager. Any procedures not complying with USATHAMA QC practices were identified to the project manager and proper corrective actions were implemented.

The project QA supervisor was required to monitor the sample preparation procedures, including sample bottle preparation, to ensure compliance with USATHAMA requirements.

The laboratory QA coordinator was required to establish sample analytical lots after the samples were logged into the laboratory. Samples were batched into lots of 10 to 14 samples. The size of the lot depended on the specific chemical analysis to be performed and the rate of sampling and chemical analysis. The field sampling schedule and shipment of samples were coordinated to meet the laboratory capacity and optimum lot sizes.

Blank samples were analyzed for all analytes with each lot. When the concentrations of target analytes exceeded the upper limit of the certified range for the analytical method, the sample extract was diluted within the certified range and reanalyzed. Resultant data were corrected for dilution factors and spike recovery.

The laboratory QA coordinator was required to assign the QC spike samples for each lot and to monitor the sample analyses to assure compliance with USATHAMA requirements. The laboratory QA coordinator was also required to monitor the chemical analysis and sampling to ensure compliance with USATHAMA holding time and preservation requirements. Problems were identified by the Project QA supervisor to the site manager, and the appropriate corrective action was implemented.

The QA/QC procedures used during Task 39 surface-water sampling are consistent with the program established for Task 4, as described above.

The QA/QC procedures followed during Task 44 used the QA/QC procedures and protocols established for the Task 4 analytical and field methods, as described above.

3.4 CMP SURFACE-WATER QUALITY

The CMP for surface water at RMA was initiated in April 1988 to provide continual and long-term monitoring of surface-water quality. The current CMP for surface water has evolved from the series of surface-water quality monitoring programs described in Section 3.3. The following sections summarize the surface-water quality monitoring network, strategies, field methods, laboratory analytical methods, and QA/QC procedures for the surface-water CMP.

3.4.1 SURFACE-WATER QUALITY MONITORING NETWORK

Sample locations for the CMP were selected from the network established during the Tasks 4 and 44 studies and supplemented with several new locations (RLSA, 1990a). Previous surface-water program sample locations were used to maintain continuous monitoring of surface-water quality baseline trends. Some locations were adjusted during FY88 to reconcile historical sample locations with current locations. The CMP surface-water sample locations relative to RMA drainage basins are illustrated in Figure 3.2-2. Surface-water quality monitoring during WY88 was planned at 36 locations (RLSA, 1990a). Surface-water sampling for WY89 was planned at 35 locations (RLSA, (1990b).

3.4.2 SURFACE-WATER QUALITY MONITORING STRATEGIES

The target analytical suite of parameters for CMP surface-water samples was based on results from sampling programs, the need to better characterize RMA surface-water quality, and allowance for comparison to the groundwater quality data. Table 3.4-1 provides the list of target analytes for the CMP surface-water samples.

Previous monitoring programs indicated that organic contaminants may have originated off post south of RMA and moved onto and across RMA through surface-water pathways. The suite of target analytes

listed in Table 3.4-1 may not include such contaminants. Consequently, the target analyte list was supplemented by GC/MS analysis of selected samples. The sampling and analytical procedures used in this program are discussed below and in Appendix B (RLSA, 1990b).

The surface-water sample locations of the CMP are shown on Figure 3.2-2. Table 3.4-2 and Table 3.4-3 summarize the frequency of water-quality sampling during WY88 and WY89, respectively. A total of 53 samples were collected from 30 locations between spring and fall of 1988. Also during WY88, four samples were collected at three stations during four storms. A total of 49 samples were collected from 29 locations between spring and fall of WY89. Also, during WY89, seven samples were collected at seven stations during three storms. Most of the sampling activities (except during storm events) conducted during the first 2 years of the CMP surface-water program were conducted with discharge measurements.

3.4.3 SURFACE-WATER QUALITY MONITORING FIELD METHODS

Surface-water sample collection and monitoring procedures and methods are described in Surface-Water Field Procedures Manual II (RLSA, 1988). The manual contains certification procedures and laboratory data forms. All collection procedures and analytical methods comply with the USATHAMA Quality Assurance Program (U.S. Army, Chemical QA Plan, 1989).

CMP stream samples were obtained by integrating samples collected over the cross section of the stream to a depth of 1 to 4 inches. When a stream was too small to collect the sample as described, it was collected from the center of the channel just below the stream surface. Lake or pond samples were collected as grab samples from near the shoreline. Parameters measured in the field during sample collection included pH, electrical conductivity and alkalinity using field instruments calibrated with known standards.

Surface-water samples were collected with a stainless steel bucket, a clean sample container, or directly into the sample bottle. Samples for organic analysis (VOA, DBCP, DCPD, organochlorines and organosulfurs) were collected in amber glass bottles with Teflon-lined caps. Samples for inorganic analysis (chloride and fluoride, total metals-unfiltered and nitrates) were collected in polyethylene containers. Dissolved metal fractions were filtered for some samples in the field using 0.45 micron nitrocellulose acetate filters. Metals fractions were preserved with dilute nitric acid to a pH of 2. The nitrates fraction was adjusted with dilute sulfuric acid to a pH of 2. All sample bottles were placed on ice in a sample cooler immediately after filling.

GC/MS (EPA 624/625) analyses were performed, in addition to analyses for target parameters, on selected surface-water samples. These samples were selected according to location of sampling site,

Table 3.4-2 Water Year 1988, Summary of Surface-Water Sampling Activities (Page 1 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS
SW01001	North Uvalda Interceptor	Ditch	Spring Fall	06/22/88 10/03/88	1 2 (including rinsate)	
SW01002	South Plants Water Tower Pond	Pond	Annual	06/21/88	1	
SW01003	South Plants Ditch	Ditch	Spring	06/21/88	Dry	
SW01004	Upper Derby Lake	Lake	Annual	06/14/88	1	
SW02001 (SW01005)	Lower Derby Lake	Lake	Annual	06/14/88	1	
SW02002	Sand Creek Lateral East	Ditch	Spring	06/15/88	1	
SW02003	Ladora Lake	Lake	Annual	06/14/88	1	
SW02004 (+ DUPE)	Lake Mary	Lake	Annual	06/14/88	2	
SW02005	Sand Creek Lateral West	Ditch	Annual	06/22/88	1	
SW02006	South Plants Steam Effluent	Ditch	Fall	10/06/88	1	
SW04001	Motor Pool	Ditch	Annual	06/21/88	Dry	
SW05001	South First Creek	Stream	Spring	06/10/88	1	1
SW07001	Uvalda Ditch A (East)	Ditch	Spring Fall	06/20/88 10/05/88	1 1	
SW07002	Uvalda Ditch B	Ditch	Spring Fall	06/20/88 10/06/88	1 1	
SW07003	Highline Lateral	Ditch	Annual	07/07/88	1	

Table 3.4-2 Water Year 1988, Summary of Surface-Water Sampling Activities (Page 2 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS
SW08001	South First Creek Boundary	Stream	Annual	06/22/88	1	
SW08002	Highline lateral South Boundary	Ditch	Annual	06/20/88	1	1
SW08003	New South First Creek	Stream	Fall	10/03/88	1	1
SW11001	Peoria Interceptor	Ditch	Spring	06/16/88	1	1
			Storm	07/08/88	1	1
			Storm	08/16/88	1	1
			Fall	10/05/88	1	1
SW11002 (+ DUPE/fall)	Havana Interceptor	Ditch	Spring	06/13/88	1	1
			Storm	07/16/88	1	1
			Fall	10/04/88	2	2
SW11003 (+ DUPE)	Havana Pond	Pond	Annual	06/15/88	4*	1
SW12001	Uvalda Ditch C	Ditch	Spring	06/20/88	1	
			Fall	10/05/88	1	
SW12002	Uvalda Ditch D	Ditch	Annual	06/22/88	Dry	
SW12003	Rod & Gun Club Pond	Pond	Annual	06/22/88	Dry	
SW12004	Storm Sewer	STSW	Spring	06/22/88	1	
			Special	07/15/88		1
			Fall	10/05/88	1 (field blank only)	
SW12005	South Uvalda	Stream	Spring	06/13/88	1	1
			Storm	07/19/88	1	
			Fall	10/04/88	1	1

Table 3.4-2 Water Year 1988, Summary of Surface-Water Sampling Activities (Page 3 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS
SW12006	Gas Spill	Ditch	Special	08/04/88	Special	
SW24001 (+ DUPE/spring)	North First Creek Sewage Treatment Plant	STP	Spring	06/16/88	2	1
			Fall	10/03/88	2 (incl. trip blank)	1
SW24002	North First Creek	Stream	Spring	06/13/88	1	1
SW24003	North Bog	Lake	Annual	06/16/88	3*	
SW30001	North Plants	Ditch	Annual	06/10/88	Dry	
SW30002	First Creek near North Plants	Stream	Annual	06/16/88	1	
SW31001	First Creek Toxic Yard A	Stream	Annual	06/21/88	Dry	
SW31002	First Creek Toxic Yard B	Pond	Annual	06/21/88	2	1
SW36001	Basin A	Ditch	Spring	06/15/88	1	
			Fall	10/04/88	1	1
SW37001	Off-Post First Creek	Stream	Spring	06/21/88	1	
			Fall	10/05/88	Dry	
				TOTALS	53	22

Source: R.L. Stollar and Associates, Inc., 1990a
GC/MS = Gas Chromatograph/Mass Spectrometer
STSW = Storm sewer
STP = Sewage Treatment Plant
* Including field blank, trip blank.

Table 3.4-3 Water Year 1989, Summary of Surface-Water Sampling Activities (Page 1 of 4)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS	Analysis: Quality Assurance
Irondale Gulch Drainage Basin							
SW01001	North Uvalda Interceptor	Ditch	Spring	04/27/89	1	1	1, (trip/GC/MS)
			Fall	09/26/89			
SW01002	South Plants Water Tower Pond	Pond	Annual	05/18/89	1	1	
SW01003	South Plants Ditch	Ditch	Spring	Dry			
			Fall	Dry			
SW01004	Upper Derby Lake	Lake	Annual	04/19/89	1		
SW01005	Lower Derby Lake	Lake	Annual	04/18/89	1 (dupe)		
SW02001	Ladora Weir	Ditch	Annual	Dry			
SW02002	Sand Creek Lateral East	Ditch	Annual	Dry			
SW02003	Ladora Lake	Lake	Annual	04/18/89	1	1	1 (rinse)
SW02004	Lake Mary	Lake	Annual	04/19/89			
SW02005	Sand Creek Lateral West	Ditch	Annual	Dry			
SW02006	South Plants Steam Effluent	Stream	Spring	04/27/89	1	1	
			Fall	09/27/89	1	1	
SW12002	Uvalda Ditch D	Ditch	Annual	Dry			
			Storm	05/15/89	1		
SW12003	Rod & Gun Club Pond	Pond	Annual	04/20/89	1		

Table 3.4-3 Water Year 1989, Summary of Surface-Water Sampling Activities (Page 2 of 4)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS	Analysis: Quality Assurance
Irondale Gulch Drainage Basin							
SW12004	Storm Sewer	STSW	Spring	04/19/89	1		
			Fall	09/26/89	1		
SW12005	South Uvalda	Stream	Spring	04/17/89	1	1	
			Storm	05/10/89	1	1	
			Fall	09/26/89	1	1	
SW12007	Highline Lateral	Ditch	Annual	Dry			
First Creek Drainage Basin							
SW08001	South First Creek Boundary	Stream	Annual	04/25/89	1	1	
SW08003	South First Creek	Stream	Spring	04/25/89	1		
			Stream	05/14/89	1	1	
			Fall	09/26/89	1 (dupe)	1 (dupe)	
SW24001	Sewage Treatment Plant	STP	Spring	04/21/89	1 (dupe)	1 (dupe)	
			Fall	09/27/89	1	1	
SW24002	North First Creek	Stream	Spring	04/21/89	1	1	
			Storm	05/15/89	1		
			Fall	Dry			
SW24003	North Bog	Lake	Annual	04/21/89	1	1	

Table 3.4-3 Water Year 1989, Summary of Surface-Water Sampling Activities (Page 3 of 4)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS	Analysis: Quality Assurance
First Creek Drainage Basin							
SW07001	Uvalda Ditch A	Ditch	Spring	04/27/89	1	1	
			Fall	09/25/89			
SW07002	Uvalda Ditch B	Ditch	Spring	Dry			
			Fall	09/25/89	1		
SW11001	Peoria Interceptor	Ditch	Spring	04/26/89	1 (dupe)	1 (dupe)	
			Storm	05/10/89	1	1	
			Fall	09/27/89	1	1	
SW11002	Havana Interceptor	Ditch	Spring	04/26/89	1	1	1 (field/GC/MS)
			Storm	05/10/89	1	1	
			Fall	09/27/89	1	1	
SW1103	Havana Pond	Pond	Annual	04/25/89	1	1	
SW12001	Uvalda Ditch C	Ditch	Spring	04/20/89	1		
			Fall	09/25/89	1		
SW24004	First Creek North Boundary	Stream	Annual	04/29/89	1		
SW30001	North Plants	Ditch	Annual	Dry			
SW30002	First Creek near North Plants	Stream	Annual	04/29/89	1		

Table 3.4-3 Water Year 1989, Summary of Surface-Water Sampling Activities (Page 4 of 4)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Analysis: Target Parameters	Analysis: GC/MS	Analysis: Quality Assurance
First Creek Drainage Basin							
SW31001	First Creek Toxic Yard A	Stream	Annual	04/25/89	1		
SW31002	First Creek Toxic Yard B	Pond	Annual	04/25/89	1		
SW37001	First Creek Off-Post	Stream	Spring	04/20/89	1	1	
South Platte Drainage Basin							
SW36001	Basin A	Ditch	Spring	04/28/89	1	1	
			Fall	09/28/89	1	1	2 (field, trip)
Sand Creek Drainage Basin							
SW04001	Motor Pool	Ditch	Annual	Dry			
			Storm	05/15/89			
				Annual Total	13	5	Rinse Total 1
				Spring Total	13	10	Field Total 2
				Storm Total	7	4	Trip Total 2
				Fall Total	12	7	
				Dupe total	4	3	
				TOTAL	49	29	5

Source: R.L. Stollar and Associates, Inc., 1990b
GC/MS = Gas Chromatograph/Mass Spectrometer
Dupe = Duplicate sample taken
STSW = Storm Sewer
STP = Sewage Treatment Plant
* Including field blank, trip blank.

historical analytical records and field conditions. The GC/MS method confirmed contaminant levels detected by other methods, and indicated the presence of nontarget compounds.

3.4.4 Laboratory Analytical Methods

Analytical method names with corresponding USATHAMA method numbers and CRLs for CMP parameters are presented in Table 3.4-1. Appendix B-7 (RLSA, 1990b) gives a brief method summary of each of the analytical methods used for DataChem Laboratories and ESE Laboratories for the chemical analysis of surface-water samples.

3.4.5 Quality Assurance/Quality Control Procedures

This section describes the implementation of QA/QC procedures in the field and laboratory that were developed for the CMP to ensure the analytical data generated are of the highest technical merit.

Quality Assurance (QA) is the program for assuring and documenting the reliability of monitoring and measurement data. QA as it relates to the analytical results generated by the CMP surface-water element assesses the data in terms of its precision, accuracy, and comparability.

Quality Control (QC) is routine application of procedures for meeting monitoring and measurement standards. QC procedures were established for analytical certification, including delineation of control limits for matrix spike and surrogate recoveries, and evaluation of method blank data for each lot of samples. The laboratory QC data are reported in weekly QA status reports that include reviews of accuracy and precision control charts. Deviations from QC criteria are evaluated by the laboratory to recommend implementation of corrective action by the laboratory QA coordinator. QC data are evaluated as unacceptable or acceptable by the project QA coordinator. The project QA coordinator then recommends the appropriate action to the PMRMA QA manager for approval and addition to the database. Any data rejected by the PMRMA QA manager is loaded into a rejected database file at DPA and is available for information only.

3.4.5.1 <u>Field Quality Control</u>

Field QC data are generated in the CMP by collecting field and trip blanks at a rate of 5 percent each of the total number of samples, and duplicate samples at a rate of 10 percent of the total.

3.4.5.1.1 Blanks

Trip blanks and field blanks are collected to evaluate the effect of contamination during sampling and transport of the field samples and the effectiveness of the sampling equipment decontamination procedures.

3.4.5.1.2 Duplicate

Duplicate samples are collected and analyzed to evaluate sampling and analytical precision. The CMP uses an order of magnitude agreement for duplicate results because guidance for agreement between organic sample and duplicate results is unavailable under the Chemical Quality Assurance Plan (CQAP) for the Rocky Mountain Arsenal. The inorganic duplicate/sample results are evaluated according to protocol outlined in the CQAP by calculating the relative difference (RD) for results greater than five times the CRL. For sample/duplicate results with values less than five times the CRL, control limits of ± the CRL are used for the assessment.

3.4.5.1.3 Gas Chromatography/Mass Spectrometry

For WY88 and WY89 of the CMP, GC/MS samples were collected and analyzed to confirm GC results and tentatively identify compound and unknown compound data for potential additions to the target analyte list.

3.4.5.2 Laboratory Quality Control

3.4.5.2.1 Analytical Quality Assurance and Quality Control

Accuracy and precision of analytical measurement is continually monitored during the CMP by analyzing spikes and surrogates with each sample lot. Accuracy is assessed by statistically evaluating recovery data from analyses of the spikes and surrogates. A 3-day moving mean is plotted on the control charts for each spike or surrogate. The following out-of-control situations are flagged:

- A value outside the control limits;
- A value classified as an outlier by statistical testing;
- A series of seven consecutive points on one side of the mean;
- A series of five successive points in the same direction; and

- Two consecutive points between the upper warning limit and upper control limit, or the lower warning limit and lower control limit.

When one of the above conditions appears on the control chart, an investigation is conducted to determine the cause and provide corrective action. This investigation sometimes indicates that control analysis, reanalysis, or resampling is required for some or all analyses associated with that QC sample. When the QC data are within control, the data are reported to the database and accuracy corrections are applied.

Precision is assessed through a range control chart of the difference between the recovery percentages for the two spiked QC samples in each lot. Out-of-control situations are flagged as follows:

- A value above control limit;

- A value considered as an outlier by statistical testing;

- A series of five consecutive points going upward;

- A cyclical pattern of control values; and

- Two consecutive points between the upper warning limit and upper control limit.

Laboratory investigations are conducted as described in the discussion of accuracy control charts, if indicated by the above conditions.

Method blanks are analyzed with each lot of samples to monitor potential sample contamination from laboratory sources. Method blank results greater than twice the analyte detection limit are subtracted from the sample results.

3.5 PRE-CMP SEDIMENT TRANSPORT STUDIES

A review of historical surface-water quality and quantity investigations showed that two sediment transport studies were performed at RMA before the CMP. These studies were part of a series of off-post investigations.

3.5.1 SCOPE OF INVESTIGATIONS

Stream-bottom sediment samples were collected at three locations along First Creek as part of the RMA off-post Contaminant Assessment Investigation (ESE, 1987c). This sampling program was conducted in conjunction with the Revision III 360 Degree Monitoring Program. Sampling was conducted in

November through December 1985 and March 1986. Sampling site 08ADD was selected to monitor sediment and water quality in First Creek as it enters RMA (Figure 3.3-1). Sampling sites 13DCC and 14BDD were selected to monitor sediment and water quality on First Creek between the north Arsenal boundary and Highway 2 (Figures 1.1-2 and 3.3-1). Correlation of these sampling sites with CMP sampling locations is provided in Section 4.3.1. Sampling was conducted on First Creek because it was identified as the primary pathway for contaminant migration from RMA.

Stream sediment samples were collected on First Creek during April 1986 as part of the off-post RI/FS (ESE, 1988e). Stream bottom sediment samples were collected on First Creek at three locations (FC1S, FC2S, and FCLS) between the north RMA boundary and Highway 2.

3.5.2 STRATEGY AND METHODS

Stream bottom sediment samples collected as part of the Revision III 360 Degree Monitoring Program on First Creek were collected at or as close to mid-channel as water levels allowed (ESE, 1987e). Sample bottles were rinsed and then filled by dipping the bottle directly into the sediments. Samples were collected by moving upstream to undisturbed sediment.

The sampling technique used during the off-post RI/FS (Task 39) was modified. Stream sediments were collected with a 6 X 6 in. Ponar dredge and then passed through a 1 millimeter (mm) polypropylene sieve to remove coarse sand, gravel, and twigs. Water from the dredged material was used to wet-sieve the samples. The sieved material was allowed to settle and the supernatant water was discarded before the sample was transferred to amber bottles and stored with ice. Loss of some colloidal material was observed in the discarded water (ESE, 1988e). The analyte schedule and CRLs used during this sediment sampling program are provided on Table 3.5-1.

3.6 CMP SEDIMENT TRANSPORT STUDY

The Surface Water CMP recognized that contaminants in RMA surface water may have a pathway through sediment transport. Sediment loading in the RMA drainages influences both the aquatic habitat and evolution of the channels. As a result of construction and remedial activities, increased loading of the streams has significantly modified the characteristics of the drainages (e.g., silting) and resulted in deposition of sediments on and downstream of RMA. This section describes the methods used to obtain sediment quantity and quality data during WY88 and WY89. The first two years of the CMP sediment transport study had three primary goals:

1) evaluate sampling equipment and methodology,
2) evaluate the bottom sediment quality, and
3) assess suspended sediment quantity along a portion of First Creek.

Table 3.5-1 Analyte Schedule and Certified Reporting Limits for Sediment Analyses Performed for Off-Post Contamination Assessment Report (Page 1 of 2)

Analytes/Methods	Certified Reporting Limit $\mu g/g$
Volatile Organic Compounds/GCMS	
1,1-Dichloroethane (11DCLE)	0.300
1,2-Dichloroethane (12DCLE)	0.300
1,1,1-Trichloroethane (111TCE)	0.300
1,1,2-Trichloroethane (112TCE)	0.300
Benzene	0.300
Bicycloheptadiene	0.300
Carbon tetrachloride	0.300
Chlorobenzene	0.300
Chloroform	0.300
Dibromochloropropane (DBCP)	0.300
Dicyclopentadiene (DCPD)	0.300
Dimethyldisulfide	0.300
Ethylbenzene	0.300
m-Xylene	0.300
Methylene chloride	0.300
Methylisobutyl ketone (MIBK)	0.300
o,p-Xylene	0.500
Tetrachloroethene (TCLEE)	0.300
Toluene	0.300
Trans 1,2-dichloroethene (12DCE)	0.300
Trichloroethene (TRCLE)	0.300
Semivolatile Organic Compounds/GCMS	
1,4-Oxathiane	0.300
2,2-Bis (para-chlorophenyl)-1,1-dichloroethane	0.400
2,2-Bis (para-chlorophenyl)-1,1,1-trichlorethane	0.300
Aldrin	0.900
Atrazine	0.700
Chlordane	1.00
Chlorophenylmethyl sulfide (CPMS)	0.300
Chlorophenylmethyl sulfoxide (CPMSO)	0.400
Chlorophenylmethyl sulfone (CPMSO2)	0.300
Dibromochloropropane (DBCP)	0.300
Dicyclopentadiene (DCPD)	0.300
Dieldrin	0.300
Diisopropylmethyl phosphonate (DIMP)	0.500
Dimethylmethyl phosphonate (DMMP)	2.00
1,4-Dithiane	0.300
Endrin	0.700
Hexachlorocyclopentadiene	1.00
Isodrin	0.300
Malathion	0.600
Parathion	0.700
Supona	0.500
Vapona	0.300

Table 3.5-1 Analyte Schedule and Certified Reporting Limits for Sediment Analyses Performed for Off-Post Contamination Assessment Report (Page 2 of 2)

Analytes/Methods	Certified Reporting Limit μg/g
Metals/ICAP	
Cadmium	0.900
Chromium	7.20
Copper	4.80
Lead	17.0
Zinc	16.0
Metals/AA	
Arsenic	4.70
Mercury	0.05

Source: ESE, 1988.

μg/g = micrograms per gram

3.6.1 SCOPE OF INVESTIGATION

Contaminants may be transported through the surface-water system by adsorption onto sediment that moves in the drainages as suspended or bed load particles. Limited data exist to evaluate the magnitude of the flow of low solubility contaminants such as heavy metals, pesticides, and semi-volatile organics. As a result of the potential importance of sediment transport and the limited amount of available information, a program was developed and initiated during WY88 and continued during WY89. The program was limited to First Creek as the pathway of fluvial sedimentation migration on and off RMA in WY88. Preliminary information on both suspended load and bed load sedimentation was collected in the first year of the study. The program during WY89 included suspended sediment sampling in Section 8 along First Creek for sediment quantity analysis and sampling bed load or bottom sediments throughout RMA at surface-water sampling locations for quality analysis (Table 3.2-1; RLSA, 1990b).

The objectives of the sediment sampling program included:

- obtaining additional baseline sediment quantity data on the transport of suspended sediments in First Creek; and

- analyzing bed load sediments to track the quality and identity of any adsorbed contaminants.

3.6.2 STRATEGY AND METHODS

Suspended sediment samples were collected using a hand-held, depth-integrating DH-48 sampler, made by Scientific Instruments and described in detail by Guy and Norman (1970). Samples were collected in the DH-48 from the middle of the creek for 10 minutes. Discharge was measured at the time of sample collection. Suspended sediment quantitative procedures are described in Appendix B-7 of the FY89 SWDAR (RLSA, 1990b). The procedures used in the collection, handling and shipment of samples are detailed in the CMP Surface-Water Field Procedures Manual. Bed load and suspended sediment samples were collected once at three locations on First Creek during the WY88 program. Eleven bed load sediment samples were collected during the spring of WY89 and five bottom sediment samples were obtained during the fall 1989 sampling round. An attempt was made to collect mobile bed materials using a Wildco server stream bottom sampler during WY88. Bed load sediment samples were also collected using a shovel during the 1988 program. Bed load or bottom sediment materials for chemical analysis were collected directly into the sample container for the 1989 program. Bottom sediment, bed load sediment, and suspended sediment samples were collected at locations outlined in Table 3.6-1 during WY88 and WY89. Analytical methods used for bottom sediment analysis during WY89 are provided on Table 3.6-2.

Table 3.6-1 Summary of Stream Sediment Sampling Activities For Water Years 1988 and 1989 (Page 1 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Sample Type: Bottom Sediments	Sample Type: Total Suspended Sediments	Sample Type: Bedload Sediments
Irondale Gulch Drainage Basin							
SW01001	North Uvalda Interceptor	Ditch	Spring	4/27/89	1		
SW01002	South Plants Water Tower Pond	Pond	Annual	5/18/89	1		
			Spring	5/18/89		1	
SW02006	South Plants Stream Effluent	Stream	Spring	4/27/89	1		
			Fall	9/27/89	1		
SW07001	Uvalda Ditch A	Ditch	Spring	4/27/89	1		
SW11001	Peoria Interceptor	Ditch	Spring	4/26/89	1		
			Fall	9/27/89	1		
SW11002	Havana Interceptor	Ditch	Spring	4/26/89	1		
SW12002	Uvalda Ditch D	Ditch	Storm	5/15/89		1	
SW12003	Rod & Gun Club Pond	Pond	Annual	4/20/89	1		
SW12004	Storm Sewer	Stsw	Spring	4/19/89	1		
SW12005	South Uvalda	Stream	Spring	4/17/89	1		
			Fall	9/26/89	1		

Table 3.6-1 Summary of Stream Sediment Sampling Activities For Water Years 1988 and 1989 (Page 2 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Sample Type: Bottom Sediments	Sample Type: Total Suspended Sediments	Sample Type: Bedload Sediments
First Creek Drainage Basin							
SW08001	South First Creek Boundary	Stream	Fall	9/29/89		1	
			Annual	4/25/89	1		
			Fall	10/25/88		1	1
SW08003	South First Creek	Stream	Spring	4/25/89	1		
			Storm	5/14/89		1	
			Fall	9/59/89	1	1	
SW08004			Fall	9/29/89		1	
SW05002			Fall	10/25/88		1	1
SW06001			Fall	10/25/88		1	1
SW24001	Sewage Treatment Plant	Stp	Spring	4/21/89		1	
SW24002	North First Creek	Stream	Spring	4/21/89	1	1	
SW30002	First Creek near North Plants	Stream	Annual	4/29/89	1		
SW31001	First Creek Toxic Yard A	Stream	Annual	4/25/89	1		
SW31002	First Creek Toxic Yard B	Pond	Annual	4/25/89	1		
SW37001	First Creek Off-Post	Stream	Spring	4/20/89	1		
SW37002			Fall	11/11/88	1		

Table 3.6-1 Summary of Stream Sediment Sampling Activities For Water Years 1988 and 1989 (Page 3 of 3)

Sample Location Number	Location Name	Site Type	Sampling Frequency		Sample Type: Bottom Sediments	Sample Type: Total Suspended Sediments	Sample Type: Bedload Sediments
South Platte Drainage Basin							
SW36001	Basin A	Ditch	Spring	4/28/89	1		
			Fall	9/28/89	1		
Sand Creek Drainage Basin							
SW04001	Motor Pool	Ditch	Storm	5/15/89		1	

Table 3.6-2 DataChem and ESE Laboratories Analytical Methods for Sediment Samples (Page 1 of 3)

Analyte Suite	Parameters	Lab.	Method* Number	Soil (µg/g) Reporting Limits (min.)	(max.)
Volatile Aromatics	Benzene	DC,ESE	AA9	0.085	5.0
	Toluene			0.19	2.0
	Chlorobenzene			-	-
	Ethylbenzene			0.16	10.0
	1,3-Xylene			0.26	5.0
	1-2-Xylene			0.39	2.0
Volatile Halocarbons	1,1-Dichloroethene	DC,ESE	NN9	0.24	5.0
	1,1-Dichloroethane			0.074	5.0
	1,2-Dichloroethene			0.26	5.0
	Chloroform			0.068	5.0
	1,2-Dichloroethane			0.85	5.0
	1,1,1-Trichloroethane			0.088	5.0
	Carbon Tetrachloride			0.12	5.0
	1,1,2-Trichloroethane			0.26	10.0
	Tetrachloroethane			0.14	10.0
	Chlorobenzene			0.20	10.0
	Methylene chloride			3.70	10.0
DBCP	1,2-Dibromo-3-chloropropane	DC,ESE	S9	0.005	0.10
Organosulfur Compounds	Dimethlydisulfide	DC,ESE	HH9A	3.12	20.0
	1,4-Oxathiane			1.74	10.0
	1,4-Dithiane			1.45	20.0
	Benzothiazole			4.40	20.0
	P-Chlorophenylmethyl sulfide			4.40	20.0
	P-Chlorophenylmethyl sulfoxide			4.81	20.0
	P-Chlorophenylmethyl sulfone			9.01	40.0
Organochlorine Pesticide	Hexachlorocyclopentadiene	DC,ESE	KK9B	0.0014	0.040
	Aldrin			0.0021	0.040
	Isodrin			0.0019	0.040
	PPDDE			0.0047	0.040
	Dieldrin			0.0018	0.040
	Endrin			0.0047	0.040
	PPDDT			0.0028	0.040
	Chlordane			0.023	0.40
Hydrocarbons	Bicycloheptadiene	DC,ESE	PP9	1.10	10.2
	Dicyclopentadiene			0.45	9.0
	Methylisobutyl ketone			0.64	10.4

* = Description of Method Number in Appendix B (RLSA, 1990b)
DC = DataChem Laboratory
ESE = Environmental Science and Engineering Laboratory

Table 3.6-2 DataChem and ESE Laboratories Analytical Methods for Sediment Samples (Page 2 of 3)

Analyte Suite	Parameters	Lab.	Method* Number	Soil (µg/g) Reporting Limits (min.)	(max.)
Anions	Bromide	DC,ESE	HHH9	-	-
	Chloride			14.00	200
	Fluoride			10.00	100
	Sulfate			88.00	1,000
Nitrate	Nitrate	-	-	-	-
Arsenic	Arsenic	DC,ESE	Y9	2.5	50.0
Mercury	Mercury	DC,ESE	Y9	0.05	1.0
ICP Metals	Cadmium	DC,ESE	P9	0.74	50.0
	Chromium			6.5	50.0
	Copper			4.7	50.0
	Lead			8.4	50.0
	Zinc			8.7	50.0
	Magnesium			-	-
	Calcium			-	-
	Sodium			-	-
	Potassium			-	-
Volatiles	1,1,1-Trichloroethane	DC,ESE	LM23	0.43	10.0
	1,1,2-Trichloroethane			0.39	25.0
	1,1-Dichloroethane			1.7	25.0
	1,1-Dichloroethene			-	-
	1,2-Dichloroethane			0.56	5.0
	1,2-Dichloroethene			-	-
	Benzene			0.25	25.0
	Carbon tetrachloride			0.25	10.0
	Chlorobenzene			1.5	10.0
	Chloroform			0.29	5.0
	Ethyl benzene			0.38	25.0
	Methylene Chloride			1.5	25.0
	Tetrachloroethene			0.25	25.0
	Toluene			0.25	25.0
	Trichloroethene			0.54	25.0
	1,3-Dimethylbenzene			0.74	10.0
	Xylene			4.9	50.0
	Methylisobutyl ketone			0.73	25.0
Semi-volatiles	Aldrin	DC,ESE	L9	0.30	99.5
	Atrazine			0.30	99.5
	Hexachlorocyclopentadiene			0.60	25.1
	Chlordane			2.0	25.1

* = Description of Method Number in Appendix B (RLSA, 1990b)
DC = DataChem Laboratory
ESE = Environmental Science and Engineering Laboratory

Table 3.6-2 DataChem and ESE Laboratories Analytical Methods for Sediment Samples (Page 3 of 3)

Analyte Suite	Parameters	Lab.	Method* Number	Soil (μg/g) Reporting Limits (min.)	(max.)
	p-Chlorophenylmethyl sulfide			0.90	99.5
	p-Chlorophenylmethyl sulfoxide			0.30	99.5
	p-Chlorophenylmethyl sulfone			0.30	99.5
	1,2-Dibromo-3-chloropropane			0.30	99.5
	Dicyclopentadiene			1.0	50.0
	Vapona			3.0	99.5
	Diisopropylmethyl phosponate			3.0	99.5
	Dithiane			0.40	99.5
	Dieldrin			3.30	99.5
	Dimethylmethyl phosphonate			-	-
	Endrin			0.30	25.1
	Isodrin			0.30	25.1
	Malathion			0.70	25.1
	Oxathiane			0.30	99.5
	PPDDE			0.60	50.0
	PDDT			0.47	25.1
	Parathion			0.90	25.1
Cyanide	Cyanide				
Nitrogen/ Phosphate Pesticides	Atrazine				
	Parathion				
	Malathion				
	Supona				
	Vapona				

* = Description of Method Number in Appendix B (RLSA, 1990b)
DC = DataChem Laboratory
ESE = Environmental Science and Engineering Laboratory

3.7 PRE-CMP GROUNDWATER AND SURFACE-WATER INTERACTION STUDIES

The first groundwater and surface-water interaction studies at RMA used water balance calculations to determine gain-loss relationships for surface-water bodies. RCI initiated a preliminary study in 1981 based on estimated inflows to RMA (RCI, 1982). With the installation of 11 new gaging stations during 1982 and 1983, RCI tried to calculate an Arsenal-wide annual water balance with the aid of monthly water quantity measurements. Water levels on Ladora Lake, Lower Derby Lake, and Havana Pond were also recorded and used in the water balance calculations. Data gaps were discovered, particularly regarding the lakes area, so the results were considered tentative.

Streamflow and water-level data collected by ESE from October 1985 to November 1987 were used to evaluate surface-water\groundwater interactions in selected areas of RMA. Upper Derby Lake, Lower Derby Lake, Ladora Lake, Lake Mary, Havana Pond, Basin A, Basin B through E, Basin F, Uvalda Interceptor, Highline Lateral, the Sewage Treatment Plant, First Creek, and North Bog were investigated. Groundwater elevation data from monitoring wells in the areas being investigated, as well as precipitation and evaporation information, were also used in the study. Gain-loss calculations were presented for Havana Pond, Upper and Lower Derby Lakes, Ladora Lake, Lake Mary, First Creek, Basin A, and Uvalda Ditch. Results and interpretations of this investigation are presented in the WRI (Ebasco, et al, 1989a).

3.8 CMP GROUNDWATER AND SURFACE-WATER INTERACTION STUDY

As part of the surface-water monitoring program, groundwater discharge and recharge were evaluated so that groundwater/surface-water interactions could be characterized. This information is necessary to assess contaminant migration onto and from RMA. Based on previous studies of groundwater and surface-water relationships, four areas were identified for monitoring during the CMP: First Creek, the area around the lakes near South Plants, Havana Pond, and the Uvalda Interceptor.

3.8.1 SCOPE OF INVESTIGATION

The prominent streams and lakes on RMA are located in the Irondale Gulch and First Creek drainage basins (Figure 1.4-1). These surface water bodies were monitored to evaluate groundwater and surface-water interactions. The following four areas are critical to the understanding of groundwater/surface-water interaction.

3.8.1.1 First Creek

First Creek crosses RMA from the southeast (Section 8) and leaves RMA in Section 24 (Figure 1.1-2). First Creek sometimes receives surface runoff from Eastern Upper Derby outflow and North Plants when

water levels are high. It sometimes receives treated effluent from the Sewage Treatment Plant in Section 24. First Creek is the primary route for surface water leaving RMA. Previous studies have suggested that both recharge and discharge of ground water occur in the First Creek drainage (RCI, 1982); therefore, this is a possible path of migration of contaminants from RMA.

3.8.1.2 South Plants Lakes

The lakes area, in the southern region of RMA south of South Plants (Figure 1.1-2), includes Eastern Upper Derby Lake, Upper Derby Lake, Lower Derby Lake, Ladora Lake, and Lake Mary. Water flows south from South Plants to Upper and Lower Derby Lakes. From Eastern Upper Derby Lake to Lake Mary, water flows from east to west. Water also flows from the south from Uvalda Interceptor to either Lower or Upper Derby Lakes. Surface water in the lakes can also be derived from Havana Pond and the Sand Creek Lateral. This water is usually placed in Ladora Lake. Much of the RMA contamination originated at South Plants; thus it is important to assess the groundwater/surface-water interaction and monitor any contamination in the area.

3.8.1.3 Havana Pond

Havana Pond is located in Section 11 near the southwest entrance of RMA. Surface water flows into Havana Pond from Havana Interceptor and Peoria Interceptor (Figure 1.1-2). Mass balance calculations and water-level data (Ebasco, et al., 1989a) strongly suggest that all of the water in the pond becomes groundwater recharge. At high flood stages, water flows from Havana Pond to the lakes area via Sand Creek Lateral, so it is important to monitor the surface-water flow in this area.

3.8.1.4 Uvalda Interceptor

Storm drainage from the Montbello residential area enters RMA from the Uvalda Interceptor (Figure 1.1-2). A consistent baseflow observed at the South Uvalda gaging station suggests that ground water is discharging to the interceptor. The year-round baseflow that has been observed at the station is unrelated to any surface runoff that may originate from the Montbello residential area.

3.8.2 Strategy and Methods

The CMP retained some of the previous methodologies used to characterize the groundwater/surface-water interaction on RMA and added several new means of evaluation. During FY88 and FY89, water levels, ion and organic data of surface-water sampling sites and groundwater wells were compared. Staff gages were used for weekly lake and pond water levels, and a Stevens Type F recorder continuously recorded levels at Havana Pond. The frequency of gathering data and the sampling network used in the groundwater/surface-water interaction study was modified slightly between FY88 (RLSA, 1990a) and

FY89 (RLSA, 1990b). Water-level data for the wells were collected in October, February, March, April, June, and September. Ion data were compiled from spring 1989 surface-water and groundwater sampling. Organic data were obtained from the spring surface-water sampling and the spring FY89 CMP groundwater sampling. A gain-loss study included discharge measurements along the southern reaches of First Creek and Uvalda Interceptor.

The groundwater wells used to help delineate groundwater/surface-water interaction were chosen on the basis of proximity to surface-water monitoring and sampling stations and are listed in Table 3.8-1. Figure 3.8-1 shows the wells chosen for this study in FY89.

Table 3.8-1 Wells Used to Delineate Groundwater/Surface-Water Interaction (FY89)

Hydrograph Data

01001, 01024, 01028 (D), 01049, 01069, 01070, 01073, 01074, 01075, 01076 (D), 02001, 02008, 02026, 02034, 02050, 02052, 02055, 02056, 02059, 02060 (D), 11002, 11007

Water Level Data

01021, 01027, 01044, 01047 (D), 02010 (D), 02020, 02022 (D), 07001, 08002, 08003, 11008, 12001, 12002, 24110, 24188, 25011, 30001, 30011 (D), 31005, 31016, 37343

Ion and Organic Data

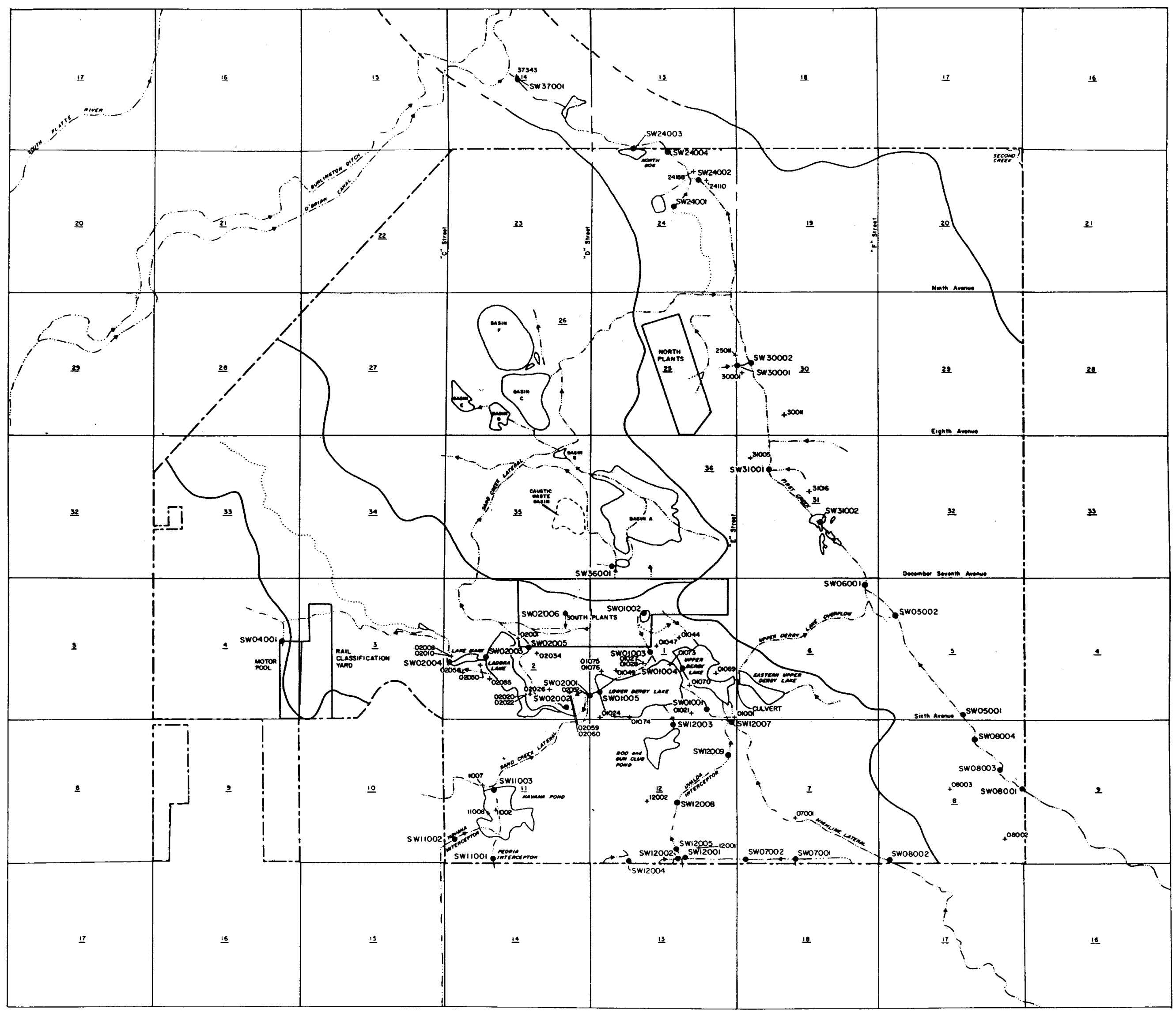
01047, 01073, 01074, 02034, 02055, 02056, 02059, 02060 (D), 24188, 31016, 37343

(D) - Well completed in the Denver Formation

3.8.2.1 Comparison of Hydrographic Data

Water levels in 43 wells were used to assess groundwater/surface-water interaction. In comparison to FY88, additional wells in the South Plants Lakes area were included in the FY89 water level network. Groundwater levels in several cluster wells in alluvial and Denver zones were measured to further characterize groundwater/surface-water interaction. Wells completed in the Denver Formation are indicated on Table 3.8-1.

Available water-level and sampling data from these wells were compared to data from adjacent surface-water monitoring stations. Hydrograph data for the South Plants Lakes and Havana Pond and adjacent wells were used to analyze communication between surface water and ground water. Additional water-level data were used to delineate areas of discharge and recharge. These wells are identified in Table 3.8-1.



Legend

- 20 — Section Number
- Lake, Pond or Basin
- Stream or Ditch with Flow Direction
- Abandoned Stream or Ditch
- SW24001 — Surface Water Sample Location
- + 24107 — Monitoring Well Location
- Arsenal Boundary
- Drainage Basin Boundary

N

0 2000 4000
FEET

Prepared for:
U.S. Army, Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 3.8-1

Location Map of Surface-Water Sampling Sites and Monitoring Wells used for Ground-Water/Surface-Water Interaction Study

CMP SW FY90H

3.8.2.2 Comparison of Ion and Organic Data

Ion and organic data were used to find areas of similar ground water and surface water compositions. Analytical results from wells were compared to analytical results from surface- water stations in the First Creek and South Plants Lakes areas. The wells are listed in Table 3.8-1. Groundwater/surface-water interaction may be indicated by similar groundwater and surface-water compositions.

In order to compare surface-water and groundwater ion data, the data were first determined to be complete and acceptable. Ion balance calculations were not performed for the fall or storm samples because concentrations of two of the anions, carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) could not be calculated from the titration endpoints reached in the laboratory. Carbonate and bicarbonate concentrations are calculated from measurements of the phenolphthalein and total alkalinities. For waters with pH less than 8.3, the total alkalinity equals the bicarbonate alkalinity (as $CaCO_3$) and there is no phenolphthalein alkalinity. Waters with a pH greater than 8.3 have a phenolphthalein alkalinity and a total alkalinity. The concentrations of each carbonate species depend on the magnitude of the two alkalinities.

In spring FY89, field alkalinity was measured in 26 surface-water samples and 11 groundwater samples. In four of the surface-water samples, the phenolphthalein alkalinity was not measured and bicarbonate concentrations could not be calculated. An ion balance was calculated on data from the remaining 22 surface-water samples and 11 groundwater samples. In general, when anion and cation data balanced to within ± 5 percent of 100 percent, the data are considered to be acceptable. A majority of the samples met this criterion and, for those that did not, the results were determined to be generally consistent with concentrations in samples from adjacent locations. To analyze groundwater/surface-water interaction, Stiff diagrams were used to compare ion concentrations in well and surface-water samples.

3.8.2.3 Gain-Loss Study

A gain-loss study on First Creek and Uvalda Interceptor during WY89 helped determine the degree of groundwater/surface-water interaction. Discharge measurements taken at three points on each of the channels were used to determine if the streams were either effluent (gaining) or influent (losing). Discharge measurement sites SW08001, SW08003 and SW08004 were chosen on First Creek, and sites SW12005, SW12008 and SW12009 were selected on Uvalda Interceptor (Figure 3.8-1). All of the discharge measurements were taken using a 200 mm long-throated flume on September 29, 1989.

4.0 RMA SURFACE-WATER DATA ASSESSMENT

4.1 PRE-CMP SURFACE-WATER QUANTITY DATA ASSESSMENT

4.1.1 STREAM FLOW DATA

A primary objective of past hydrologic studies was to develop an accurate water balance of the surface-water flow entering and exiting RMA. Surface-water flow data were collected by several contracted consulting firms and RMA personnel during WY82 through WY87. The monitoring stations were not equipped to operate under freezing conditions generally resulting in the network being shut down from the beginning of December to the end of March. During this period, stream staff gages were read weekly and estimated flow values were reported in an attempt to provide a nearly continuous yearly record (Ebasco, 1989a). Other data gaps existed due to problems such as equipment malfunctions.

The available pre-CMP flow data, consisting of mean daily flows and total monthly volumes, were compiled and summarized for WY82 through WY87 (Table 4.1-1). Historical discharge data reported for December 1982 through March 1983 are based on estimated daily flow values during this period. Flow values shown on this table were derived from values reported by RCI and ESE, Inc. This evaluation was intended to document how previously reported data were collected and to provide a data summary. The investigation of pre-CMP flow data noted the following:

- Continuous data were typically available for April through November. Freezing conditions in stilling wells and intake pipes during the remainder of the year made the stations inoperable.

- Winter month (December through April) flow records are estimated for the WY83, WY86, and WY87. A limited number of visual observations were taken during the winter months. Although daily flow values are reported in historical flow data documents for these months, the values are not reliable when visual observations were not made.

TABLE 4.1-1 (Page 1 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

BASIN A		WY1982[1]	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		19			31	31
	Total (ac-ft)		0.46			0.58	0.79
	Min (cfs)		T			0.01	0.00
	Max (cfs)		0.15			0.02	0.06
NOVEMBER	Days of Record		18			30	30
	Total (ac-ft)		0.10			0.56	0.67
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.05			0.03	0.09
DECEMBER+	Days of Record		31			31	31
	Total (ac-ft)		1.24			0.09	0.18
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.43			0.00	0.02
JANUARY+	Days of Record		28			31	31
	Total (ac-ft)		0.03			0.09	0.09
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.02			0.00	0.00
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		0.04			0.08	0.08
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.02			0.00	0.00
MARCH+	Days of Record		31			31	31
	Total (ac-ft)		2.30			0.14	0.09
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.29			0.01	0.00
APRIL	Days of Record	1	30			30	30
	Total (ac-ft)	0.00	0.97			4.31	0.42
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.00	0.27			0.46	0.05
MAY	Days of Record	11	29			31	31
	Total (ac-ft)	0.00	2.80			1.04	2.19
	Min (cfs)	0.00	T			0.01	0.00
	Max (cfs)	0.15	0.67			0.13	0.33
JUNE	Days of Record		29			30	30
	Total (ac-ft)		1.01			0.91	1.68
	Min (cfs)		T			0.01	0.01
	Max (cfs)		0.36			0.12	0.22
JULY	Days of Record		31			31	31
	Total (ac-ft)		0.85			0.77	0.69
	Min (cfs)		T			0.00	0.01
	Max (cfs)		0.34			0.11	0.04
AUGUST	Days of Record	29	28			31	31
	Total (ac-ft)	0.47	0.31			0.84	1.06
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.16	0.13			0.21	0.22
SEPTEMBER	Days of Record	30	28			30	30
	Total (ac-ft)	0.45	0.11			0.19	2.30
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.12	0.06			0.02	0.14

T = Trace Flow; + = Estimated daily flow values recorded during this month.
1 = Source: RCI, 1983; 2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 2 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

HAVANA INTERCEPTOR		WY1982	WY1983	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 29.80 0.00 4.20	31 88.60 0.70 4.50
NOVEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 136.30 0.00 14.40	31 53.80 0.10 3.60
DECEMBER+	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 69.2 0.3 5.7	31 22.0 0.1 4.8
JANUARY+	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 0.2 0.00 0.1	31 4.1 0.0 0.3
FEBRUARY+	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					28 0.8 0.0 0.1	28 3.8 0.0 0.3
MARCH+	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 17.8 0.00 4.7	31 121.5 0.1 6.5
APRIL	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 358.70 0.00 62.80	30 77.40 0.00 10.40
MAY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 95.10 0.00 10.30	31 276.60 1.00 20.90
JUNE	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 77.50 0.70 6.30	30 293.90 1.30 31.70
JULY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 113.70 0.80 7.20	31 119.10 1.00 4.90
AUGUST	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 118.60 0.70 11.20	31 113.00 0.00 12.20
SEPTEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 70.50 0.70 3.00	30 102.40 0.70 8.90

+ = Estimated daily flow values recorded during this month.
3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 3 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

HIGHLINE LATERAL		WY1982	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		31			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
NOVEMBER	Days of Record		30			30	30
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
DECEMBER+	Days of Record		31			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
JANUARY+	Days of Record		31			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
MARCH+	Days of Record		31			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
APRIL	Days of Record		30			30	30
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	0.00
MAY	Days of Record		31			31	31
	Total (ac-ft)		91.84			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		14.93			0.00	0.00
JUNE	Days of Record		30			30	30
	Total (ac-ft)		0.00			0.00	262.60
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	11.80
JULY	Days of Record		31			31	31
	Total (ac-ft)		0.00			145.10	148.40
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			13.50	11.30
AUGUST	Days of Record		31			31	31
	Total (ac-ft)		0.00			0.00	51.10
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			0.00	7.90
SEPTEMBER	Days of Record		30			30	30
	Total (ac-ft)		0.00			162.70	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		0.00			12.50	0.00

+ = Estimate daily flow values recorded during this month.
2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 4 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow, Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

LADORA WEIR		WY1982[1]	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		31			31	
	Total (ac-ft)		38.94			10.40	5.10
	Min (cfs)		T			0.00	0.00
	Max (cfs)		3.30			2.70	2.60
NOVEMBER	Days of Record		19			30	
	Total (ac-ft)		16.05			1.54	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		3.12			0.80	0.00
DECEMBER+	Days of Record		30			31	31
	Total (ac-ft)		11.89			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		3.38			0.00	0.00
JANUARY+	Days of Record		28			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		T			0.00	0.00
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		T			0.00	0.00
MARCH+	Days of Record		3			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		T			0.00	0.00
APRIL	Days of Record		30			30	30
	Total (ac-ft)		23.63			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		6.97			0.00	0.00
MAY	Days of Record		29			31	31
	Total (ac-ft)		0.00			0.00	0.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		T			0.00	0.00
JUNE	Days of Record		29			30	30
	Total (ac-ft)		0.00			0.00	53.00
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		T			0.00	13.60
JULY	Days of Record		31			31	31
	Total (ac-ft)		20.92			19.80	82.10
	Min (cfs)		0.00			0.00	0.00
	Max (cfs)		5.79			5.10	14.50
AUGUST	Days of Record	27	28			31	31
	Total (ac-ft)	71.09	0.00			20.40	0.00
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	2.99	T			5.00	0.00
SEPTEMBER	Days of Record	30	28			30	30
	Total (ac-ft)	70.64	46.00			23.90	1.10
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	3.37	10.11			6.90	0.10

T = Trace Flow; E = Estimated daily flow data during this month.
1 = Source: RCI, 1983; 2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 5 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

NORTH UVALDA		WY1982[1]	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		31			31	
	Total (ac-ft)		6.91			25.90	25.80
	Min (cfs)		T			0.30	0.20
	Max (cfs)		2.39			1.10	1.20
NOVEMBER	Days of Record		19			30	
	Total (ac-ft)		0.47			54.20	16.70
	Min (cfs)		T			0.40	0.20
	Max (cfs)		0.20			3.60	1.40
DECEMBER+	Days of Record		22			31	31
	Total (ac-ft)		1.01			45.1	14.4
	Min (cfs)		T			0.3	0.2
	Max (cfs)		0.24			2.9	0.7
JANUARY+	Days of Record		6			31	31
	Total (ac-ft)		38.40			22.6	11.3
	Min (cfs)		1.32			0.3	0.1
	Max (cfs)		7.59			0.4	0.3
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		44.42			17.5	8.9
	Min (cfs)		0.19			0.3	0.1
	Max (cfs)		6.70			0.4	0.2
MARCH+	Days of Record		31			31	31
	Total (ac-ft)		41.18			17.6	7.5
	Min (cfs)		0.03			0.3	0.1
	Max (cfs)		3.70			0.5	0.2
APRIL	Days of Record	2*	30			30	30
	Total (ac-ft)	0.00*	15.09			51.70	10.50
	Min (cfs)	0.00*	T			0.30	0.10
	Max (cfs)	0.00*	1.54			2.80	1.40
MAY	Days of Record	31*	29			31	31
	Total (ac-ft)	16.15*	9.87			34.00	39.60
	Min (cfs)	0.00*	T			0.30	0.10
	Max (cfs)	2.37*	1.98			3.60	3.90
JUNE	Days of Record	30*	29			30	30
	Total (ac-ft)	30.87*	24.06			18.70	306.00
	Min (cfs)	0.00*	T			0.20	0.20
	Max (cfs)	2.38*	9.90			2.20	26.00
JULY	Days of Record	31*	29			31	31
	Total (ac-ft)	13.13*	32.76			171.40	126.60
	Min (cfs)	0.00*	0.18			0.20	0.10
	Max (cfs)	0.74*	8.57			15.00	12.40
AUGUST	Days of Record	27	3			31	31
	Total (ac-ft)	19.78	1.13			27.10	75.20
	Min (cfs)	0.00	0.18			0.20	0.00
	Max (cfs)	9.23	0.19			4.30	16.70
SEPTEMBER	Days of Record	30				30	30
	Total (ac-ft)	8.70				202.40	16.30
	Min (cfs)	0.00				0.20	0.00
	Max (cfs)	0.57				14.70	3.00

* North Uvalda Gage at old location.

T = Trace Flow; + = Estimated daily flow values during this period.

1 = Source: RCI, 1983; 2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 6 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

PEORIA INTERCEPTOR		WY1982	WY1983	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record					31	31
	Total (ac-ft)					6.90	12.90
	Min (cfs)					0.00	0.00
	Max (cfs)					1.10	2.00
NOVEMBER	Days of Record					30	30
	Total (ac-ft)					3.40	7.40
	Min (cfs)					0.00	0.00
	Max (cfs)					0.60	1.30
DECEMBER+	Days of Record					31	31
	Total (ac-ft)					0.30	0.50
	Min (cfs)					0.00	0.00
	Max (cfs)					0.10	0.20
JANUARY+	Days of Record					31	31
	Total (ac-ft)					0.00	0.00
	Min (cfs)					0.00	0.00
	Max (cfs)					0.00	0.00
FEBRUARY+	Days of Record					28	28
	Total (ac-ft)					0.00	1.50
	Min (cfs)					0.00	0.00
	Max (cfs)					0.00	0.40
MARCH+	Days of Record					31	31
	Total (ac-ft)					1.90	69.2
	Min (cfs)					0.00	0.00
	Max (cfs)					0.80	4.10
APRIL	Days of Record					30	30
	Total (ac-ft)					26.20	9.00
	Min (cfs)					0.00	0.00
	Max (cfs)					3.30	1.50
MAY	Days of Record					31	31
	Total (ac-ft)					10.40	37.80
	Min (cfs)					0.00	0.00
	Max (cfs)					2.90	5.60
JUNE	Days of Record					30	30
	Total (ac-ft)					7.30	13.00
	Min (cfs)					0.00	0.00
	Max (cfs)					1.60	2.00
JULY	Days of Record					31	31
	Total (ac-ft)					17.00	19.20
	Min (cfs)					0.00	0.00
	Max (cfs)					4.90	4.90
AUGUST	Days of Record					31	31
	Total (ac-ft)					14.60	40.90
	Min (cfs)					0.00	0.00
	Max (cfs)					4.80	7.60
SEPTEMBER	Days of Record					30	30
	Total (ac-ft)					4.10	0.00
	Min (cfs)					0.00	0.00
	Max (cfs)					0.70	0.00

+ = Estimated daily flow values recorded during this month.
3 = Source: Ebasco, 1989a

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PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH FIRST CREEK		WY1982[1]	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		31			31	31
	Total (ac-ft)		0.00			68.10	29.20
	Min (cfs)		0.00			0.70	0.20
	Max (cfs)		T			1.60	1.00
NOVEMBER	Days of Record		19			30	30
	Total (ac-ft)		0.00			92.70	53.70
	Min (cfs)		0.00			0.90	0.70
	Max (cfs)		T			3.40	1.40
DECEMBER+	Days of Record		30			31	31
	Total (ac-ft)		0.00			116.3	67.40
	Min (cfs)		0.00			0.30	0.70
	Max (cfs)		T			2.60	1.50
JANUARY+	Days of Record		29			31	31
	Total (ac-ft)		91.59			99.60	139.80
	Min (cfs)		0.00			0.30	1.10
	Max (cfs)		21.21			2.60	5.00
FEBRUARY+	Days of Record		28			27	27
	Total (ac-ft)		0.73			100.80	67.80
	Min (cfs)		T			1.10	1.10
	Max (cfs)		0.37			2.60	1.50
MARCH+	Days of Record		31			31	31
	Total (ac-ft)		37.25			65.00	82.90
	Min (cfs)		T			0.70	1.10
	Max (cfs)		4.82			1.50	1.50
APRIL	Days of Record	2	30			30	30
	Total (ac-ft)	0.00	176.61			301.40	68.00
	Min (cfs)	0.00	T			0.70	0.70
	Max (cfs)	0.00	12.07			41.00	1.80
MAY	Days of Record	31	22			31	31
	Total (ac-ft)	1.71	430.91			95.00	222.40
	Min (cfs)	0.00	3.84			1.10	0.80
	Max (cfs)	0.76	94.49			3.90	36.30
JUNE	Days of Record	30	29			30	30
	Total (ac-ft)	4.37	122.78			49.20	239.30
	Min (cfs)	0.00	T			0.00	0.30
	Max (cfs)	1.84	7.46			2.60	71.80
JULY	Days of Record	31	26			31	31
	Total (ac-ft)	0.45	81.92			3.90	21.40
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.23	31.77			0.40	2.70
AUGUST	Days of Record	31	23			31	31
	Total (ac-ft)	5.34	214.17			6.70	6.30
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	2.34	61.80			1.40	1.10
SEPTEMBER	Days of Record	30	29			30	30
	Total (ac-ft)	119.07	0.00			7.60	4.40
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	50.79	T			0.90	0.20

T = Trace Flow; + = Estimated daily flow values recorded during this month.
1 = Source: RCI, 1983; 2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 8 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH PLANTS DITCH		WY1982[1]	WY1983[2]	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		12			31	31
	Total (ac-ft)		12.67			0.00	0.00
	Min (cfs)		0.46			0.00	0.00
	Max (cfs)		0.96			0.00	0.00
NOVEMBER	Days of Record		19			30	30
	Total (ac-ft)		17.44			0.00	0.00
	Min (cfs)		0.46			0.00	0.00
	Max (cfs)		0.49			0.00	0.00
DECEMBER+	Days of Record		22			31	31
	Total (ac-ft)		2.49			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.42			0.00	0.00
JANUARY+	Days of Record		27			31	31
	Total (ac-ft)		1.51			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.38			0.00	0.00
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		5.26			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.56			0.00	0.00
MARCH+	Days of Record		20			31	31
	Total (ac-ft)		3.62			0.00	0.00
	Min (cfs)		T			0.00	0.00
	Max (cfs)		0.46			0.00	0.00
APRIL	Days of Record	2	29			30	30
	Total (ac-ft)	0.30	26.74			0.00	0.00
	Min (cfs)	0.00	0.46			0.00	0.00
	Max (cfs)	0.15	0.53			0.00	0.00
MAY	Days of Record	31	29			31	31
	Total (ac-ft)	27.67	35.14			0.00	0.00
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.61	1.05			0.00	0.00
JUNE	Days of Record	30	29			30	30
	Total (ac-ft)	19.15	34.90			0.00	0.00
	Min (cfs)	0.00	0.15			0.00	0.00
	Max (cfs)	0.60	1.05			0.00	0.00
JULY	Days of Record	31	31			31	31
	Total (ac-ft)	4.73	0.91			0.00	0.00
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.60	0.21			0.00	0.00
AUGUST	Days of Record	31	29			31	31
	Total (ac-ft)	17.96	37.87			0.00	0.00
	Min (cfs)	0.00	T			0.00	0.00
	Max (cfs)	0.52	1.37			0.00	0.00
SEPTEMBER	Days of Record	20	28			30	30
	Total (ac-ft)	9.51	35.74			0.00	0.00
	Min (cfs)	T	T			0.00	0.00
	Max (cfs)	0.56	1.24			0.00	0.00

T = Trace Flow; + = Estimated daily flow values recorded during this month.
1 = Source: RCI, 1983; 2 = Source RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 9 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH UVALDA		WY1982	WY1983	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record		31			31	
	Total (ac-ft)		15.21			37.40	49.00
	Min (cfs)		T			0.40	0.40
	Max (cfs)		3.97			2.80	3.50
NOVEMBER	Days of Record		18			30	
	Total (ac-ft)		2.68			34.20	27.10
	Min (cfs)		T			0.40	0.30
	Max (cfs)		1.22			1.50	1.60
DECEMBER+	Days of Record		30			31	31
	Total (ac-ft)		81.02			27.00	22.60
	Min (cfs)		T			0.40	0.30
	Max (cfs)		10.71			0.60	1.10
JANUARY+	Days of Record		28			31	31
	Total (ac-ft)		99.55			24.90	20.80
	Min (cfs)		T			0.40	0.30
	Max (cfs)		13.80			0.50	0.40
FEBRUARY+	Days of Record		28			28	28
	Total (ac-ft)		8.74			22.20	18.20
	Min (cfs)		T			0.40	0.30
	Max (cfs)		1.97			0.40	0.40
MARCH+	Days of Record		31			31	31
	Total (ac-ft)		75.52			29.80	46.80
	Min (cfs)		T			0.40	0.30
	Max (cfs)		9.53			1.30	1.20
APRIL	Days of Record		30			30	30
	Total (ac-ft)		8.47			147.20	33.90
	Min (cfs)		T			0.40	0.30
	Max (cfs)		1.18			25.80	2.50
MAY	Days of Record	17	29			31	31
	Total (ac-ft)	8.00	29.90			56.80	94.80
	Min (cfs)	0.00	T			0.60	0.40
	Max (cfs)	1.00	4.32			5.30	11.10
JUNE	Days of Record	30	29			30	30
	Total (ac-ft)	21.67	7.32			58.30	89.80
	Min (cfs)	0.00	T			0.60	0.20
	Max (cfs)	3.24	1.61			6.00	9.40
JULY	Days of Record	31	31			31	31
	Total (ac-ft)	1.91	5.15			73.30	48.90
	Min (cfs)	0.00	T			0.50	0.40
	Max (cfs)	0.62	0.98			8.30	4.50
AUGUST	Days of Record	31	29			31	31
	Total (ac-ft)	22.33	1.81			75.40	134.50
	Min (cfs)	T	T			0.50	0.60
	Max (cfs)	8.42	0.39			14.90	38.30
SEPTEMBER	Days of Record	30	28			30	30
	Total (ac-ft)	9.34	0.56			34.80	61.80
	Min (cfs)	T	T			0.40	0.30
	Max (cfs)	1.45	0.20			0.80	5.70

T = Trace Flow; + = Estimated daily flow values recorded during this period.
1 = Source: RCI, 1983; 2 = Source: RCI, 1984; 3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 10 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

FIRST CREEK - OFF-POST		WY1982	WY1983	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record						31
	Total (ac-ft)						0.02
	Min (cfs)						0.00
	Max (cfs)						0.00
NOVEMBER	Days of Record						30
	Total (ac-ft)						1.09
	Min (cfs)						0.01
	Max (cfs)						0.03
DECEMBER+	Days of Record						31
	Total (ac-ft)						3.27
	Min (cfs)						0.03
	Max (cfs)						0.06
JANUARY+	Days of Record						31
	Total (ac-ft)						5.28
	Min (cfs)						0.06
	Max (cfs)						0.36
FEBRUARY+	Days of Record						28
	Total (ac-ft)						27.97
	Min (cfs)						0.36
	Max (cfs)						0.82
MARCH+	Days of Record						31
	Total (ac-ft)						52.94
	Min (cfs)						0.56
	Max (cfs)						1.13
APRIL	Days of Record						30
	Total (ac-ft)						51.45
	Min (cfs)						0.46
	Max (cfs)						1.69
MAY	Days of Record						31
	Total (ac-ft)						159.21
	Min (cfs)						0.42
	Max (cfs)						11.57
JUNE	Days of Record						30
	Total (ac-ft)						109.97
	Min (cfs)						0.07
	Max (cfs)						15.97
JULY	Days of Record					31	31
	Total (ac-ft)					0.76	5.16
	Min (cfs)					0.00	0.00
	Max (cfs)					0.02	0.82
AUGUST	Days of Record					31	NR
	Total (ac-ft)					0.00	
	Min (cfs)					0.00	
	Max (cfs)					0.00	
SEPTEMBER	Days of Record					30	NR
	Total (ac-ft)					0.00	
	Min (cfs)					0.00	
	Max (cfs)					0.00	

+ = Estimated daily flow values recorded during this period; NR = Not Recorded.
3 = Source: Ebasco, 1989a

TABLE 4.1-1 (Page 11 of 11)

PRE-CMP FLOW DATA

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

NORTH FIRST CREEK		WY1982	WY1983	WY1984	WY1985	WY1986[3]	WY1987[3]
OCTOBER	Days of Record					31	31
	Total (ac-ft)					65.00	0.00
	Min (cfs)					0.50	0.00
	Max (cfs)					2.40	0.00
NOVEMBER	Days of Record					30	30
	Total (ac-ft)					193.80	0.00
	Min (cfs)					1.50	0.00
	Max (cfs)					6.40	0.00
DECEMBER+	Days of Record					31	31
	Total (ac-ft)					127.50	0.00
	Min (cfs)					0.00	0.00
	Max (cfs)					6.20	0.00
JANUARY+	Days of Record					31	31
	Total (ac-ft)					195.30	20.40
	Min (cfs)					1.50	0.00
	Max (cfs)					5.00	1.10
FEBRUARY+	Days of Record					28	28
	Total (ac-ft)					87.20	55.80
	Min (cfs)					1.50	0.50
	Max (cfs)					2.10	2.80
MARCH+	Days of Record					31	31
	Total (ac-ft)					61.80	99.20
	Min (cfs)					0.50	1.10
	Max (cfs)					2.10	2.80
APRIL	Days of Record					30	30
	Total (ac-ft)					262.90	63.70
	Min (cfs)					0.50	0.50
	Max (cfs)					15.90	1.60
MAY	Days of Record					31	31
	Total (ac-ft)					69.50	253.90
	Min (cfs)					0.10	0.10
	Max (cfs)					4.50	31.20
JUNE	Days of Record					30	30
	Total (ac-ft)					5.40	257.50
	Min (cfs)					0.00	0.00
	Max (cfs)					0.50	80.90
JULY	Days of Record					31	31
	Total (ac-ft)					0.00	0.10
	Min (cfs)					0.00	0.10
	Max (cfs)					0.00	0.00
AUGUST	Days of Record					31	NR
	Total (ac-ft)					0.00	
	Min (cfs)					0.00	
	Max (cfs)					0.00	
SEPTEMBER	Days of Record					30	NR
	Total (ac-ft)					0.00	
	Min (cfs)					0.00	
	Max (cfs)					0.00	

+ = Estimated daily flow values recorded during this period; NR = Not Recorded.
3 = Source: Ebasco, 1989a

- During April through November, there were several days when no gage-height record was obtained or estimated.

- Strip chart recordings of continuous stage (gage height) for WY84 and WY85 were never reduced for calculation of discharge values. These data cannot be recovered accurately because almost no records are available to document stage-discharge relationships, or problems affect strip chart recordings or the relationship between strip chart stage and actual stream or rating stage.

Accurate evaluation of annual trends is impossible because of the lack of complete yearly records. Qualitative analysis of the available flow data could identify possible diurnal, monthly, and season trends for April through November. The qualitative analysis should be limited to identifying:

- periods when flow was encountered at gaged sites;

- periods of zero flow, baseflow, and high flow; and

- correlations of flow events (watershed response) to meteorological conditions (freezing snow, melt runoff, rainfall, drought).

A detailed review and evaluation was performed on stage and discharge records for the South Uvalda gaging station to evaluate reported historical flow measurement records. The procedures used and the results of this review are discussed in the next two sections (4.1.1.1 and 4.1.1.1.1).

4.1.1.1 South Uvalda Stage Record Review Procedures

The objectives of this review were to determine if: (1) historical strip charts for October 1985 through September 1987 were accurately reduced; and (2) the resulting records were accurately converted to discharge record.

An initial examination of historical strip charts indicated that historical data reduction methods were consistent for the continuous stage recording stations, and that any significant errors in these methods

discovered at one station would be applicable to all stations. Therefore, the most efficient approach to the historical review would be reanalysis of strip charts, stage and discharge records for a single station.

The South Uvalda (SW12005) gaging station records were selected for reanalysis because:

- They are integral to the CMP, since the South Uvalda gaging station is on a significant drainage conveying flow onto the RMA;

- South Uvalda flow is significantly affected by urban runoff, which results in large peak events, rapid fluctuation in flow, and longer periods of sustained flow; and

- Historical inaccuracies in record keeping, data reduction, and rating relationships are more easily identifiable at a station experiencing the previously described flow-regime variability.

The South Uvalda gaging record review involved a preliminary and a subsequent detailed analysis of the gaging records from October 1985 through September 1987. The preliminary analysis involved the following procedures:

- Strip charts were checked for continuity between starting and ending times and stage notations with respect to the trace on the strip chart;

- Baseline shifts were identified;

- Strip charts were checked for errors, missing notation, and equipment malfunctions; and

- Strip charts and field notes were reviewed to identify periods of questionable stage records caused by channel changes (e.g., debris in control structure).

Initially the preliminary analysis evaluated eight strip charts that represented seasonal flow extremes, including steady baseflow periods and periods of rapidly fluctuating flow. If obvious errors in chart

annotation and data reduction methods were identified in this group, the credibility of all historical gaging records would be questionable.

Since no significant problems were found in the preliminary analysis of the initial eight strip charts, a more detailed analysis was conducted of all the records for South Uvalda. The detailed analysis included the following:

- The preliminary analysis (as described above) was conducted on all charts;
- All charts were digitized to support a detailed comparison of digitized stage records to the historical records that were generated using a manual method;
- The historical stage record, which was originally generated manually to the nearest 0.05 ft, was compared to the newly digitized records. This included:
  - comparison of the magnitude of the instantaneous peak stages;
  - comparison of the timing of the instantaneous peak stages; and
  - general comparison of all stage data.
- The historical discharge records were compared to the newly computed discharge records. The new discharge records were prepared by applying the current applicable WY89 rating curve to the newly digitized stage record. This comparison included:
  - minimum and maximum monthly instantaneous discharges;
  - minimum and maximum daily mean discharges; and
  - total monthly flow volumes in acre-feet (ac-ft).

4.1.1.1.1 South Uvalda Historical Stage Data Review Results

The South Uvalda (SW12005) gaging station records for October 1985 through September 1987 were selected for reanalysis. As discussed in Section 4.1.1.1, a preliminary analysis led to a check of all strip chart: for starting and ending notations, baseline corrections, errors, recorder malfunctions, and channel obstructions. The results of this analysis are summarized for all 80 strip charts in Table 4.1-2 (Historical Strip Chart Reduction Preliminary Analysis). The most apparent discrepancy was in the baseline notations, which often required corrections. A few strip charts were found to have missing starting and ending notations, recorder malfunctions, and/or channel obstructions. However, none of the errors or problems identified in the original historical strip chart review were significant enough to discredit the historical data.

Subsequently, the South Uvalda strip charts for October 1985 through September 1987 were digitized to allow comparison of stage and discharge between the digitized and historical (manually reduced) records. This comparison is discussed in Section 4.1.1.1.

The criteria for stage comparisons were based on whether: a) historical and digitized stage records compared to within ±0.05 ft; b) stage records compared to within ±0.10 ft; c) times of the recorded peak were within ±1 hour; and d) times of the recorded peak were within ±2 hours.

These criteria were chosen because the historical stage records were rounded to the nearest ±0.05 ft, and it was desirable to make a check at that precision. The ±0.10 ft criterion was set subjectively at twice the ±0.05 ft increment. In addition, the historical records were reduced to show 24 hourly increments each day; the comparison is based on the hourly increment. A ±2-hour comparison was subjectively chosen as twice the hourly increment, and also to reflect possible differences in records converted to standard time (all digital records) versus those reflecting daylight savings time periods (some historical records).

When stage records are converted to discharge records, the historical discharge values (instantaneous peak, daily means and total volumes) should be within 10-percent of the newly digitized discharge values to be considered acceptable. The 10-percent criterion was chosen because the previous ±0.05-ft stage criterion was generally equivalent to a 10-percent change in discharge relevant to the historical rating relationship.

Table 4.1-2 Comparison of Instantaneous Peak Stages, South Uvalda

	Historical Record		Digitized Record				
Date	Time (hrs)	Peak Stage (ft)	Time (hrs)	Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
10/01/85	14.00	4.20	14.23	4.18	0.23	-0.02	
10/11/85	5.00	4.60	4.78	4.77	-0.22	0.17	
10/11/85	10.00	4.20	10.38	4.30	0.38	0.10	
10/13/85	13.00	4.25	12.80	4.28	-0.20	0.03	
10/13/85	21.00	4.65	21.69	4.68	0.69	0.03	
10/14/85	12.00	4.10	12.44	4.15	0.44	0.05	
10/31/85	17.00	5.00	17.70	5.06	0.70	0.06	
10/31/85	19.00	4.80	19.50	4.86	0.50	0.06	
11/09/85	9.00	4.65	9.57	4.73	0.57	0.08	
11/09/85	15.00	4.20	15.83	4.21	0.83	0.01	
11/10/85	14.00	4.10	13.90	4.13	-0.10	0.03	
11/11/85	14.00	4.25	13.92	4.27	-0.08	0.02	
11/15/85	12.00	4.70	12.06	4.73	0.06	0.03	
11/19/85	14.00	4.15	13.67	4.17	-0.33	0.02	
11/20/85	14.00	4.15	13.71	4.19	-0.29	0.04	
11/25/85	13.00	4.30	13.92	4.31	0.92	0.01	
12/15/85	16.00	4.05	16.41	4.08	0.41	0.03	
03/17/86	0.00	4.20	0.55	4.38	0.55	0.18	
03/17/86	12.00	4.75	12.19	4.82	0.19	0.07	
03/19/86	18.00	4.25	18.28	4.30	0.28	0.05	
03/20/86	10.00	4.25	23.84	4.21	-10.16	-0.04	Digitized Peak on 03/19/86
03/20/86	9.00	4.30	8.76	4.28	-0.24	-0.02	
04/02/86	19.00	5.50	19.60	5.87	0.60	0.37	
04/04/86	15.00	5.70	16.58	5.81	1.58	0.11	
04/05/86	11.00	5.15	12.08	5.19	1.08	0.04	
04/06/86	14.00	4.85	14.37	4.84	0.37	-0.01	
04/07/86	15.00	4.65	14.54	4.67	-0.46	0.02	
04/09/86	8.00	4.60	7.30	4.61	-0.70	0.01	
04/11/86	21.00	4.65	20.34	4.88	-0.66	0.23	
04/17/86	12.00	5.10	12.94	5.16	0.94	0.06	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.

TB2-HIST.SW

Table 4.1-2 Comparison of Instantaneous Peak Stages, South Uvalda (continued)

Date	Historical Record Time (hrs)	Historical Record Peak Stage (ft)	Digitized Record Time (hrs)	Digitized Record Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
04/20/86	24.00	4.90	1.33	4.92	1.33	0.02	Digitized peak on 04/21/86
04/26/86	12.00	4.40	16.69	4.67	4.69	0.27	
05/08/86	3.00	4.30	2.16	4.45	-0.84	0.15	
05/08/86	15.00	4.85	15.96	4.88	0.96	0.03	
05/15/86	14.00	4.85	14.15	5.17	0.15	0.32	
05/16/86	3.00	4.95	3.94	5.05	0.94	0.10	
06/02/86	1.00	4.60	1.37	4.74	0.37	0.14	
06/02/86	7.00	4.35	7.57	4.31	0.57	-0.04	
06/08/86	18.00	4.60	18.84	4.72	0.84	0.12	
06/09/86	10.00	4.25	10.73	4.28	0.73	0.03	
06/10/86	7.00	5.15	8.08	5.20	1.08	0.05	
06/16/86	21.00	4.40	22.05	4.67	1.05	0.27	
07/05/86	20.00	4.70	20.01	4.83	0.01	0.13	
07/16/86	18.00	4.50	19.27	4.36	1.27	-0.14	
07/17/86	20.00	5.85	21.10	6.38	1.10	0.53	
07/20/86	20.00	4.95	20.76	5.01	0.76	0.06	
07/22/86	20.00	4.45	20.45	4.49	0.45	0.04	
08/02/86	20.00	6.25	21.35	6.60	1.35	0.35	
08/16/86	22.00	4.15	22.45	4.17	0.45	0.02	
08/22/86	21.00	4.80	21.71	4.83	0.71	0.03	
08/29/86	18.00	4.40	18.81	4.41	0.81	0.01	
09/07/86	24.00	4.35	23.83	4.39	-0.17	0.04	
09/24/86	14.00	4.10	14.42	4.13	0.42	0.03	
10/03/86	6.00	4.20	6.94	4.20	0.94	0.00	
10/03/86	23.00	4.35	23.93	4.34	0.93	-0.01	
10/09/86	1.00	4.35	1.92	4.35	0.92	0.00	
10/10/86	21.00	5.15	22.10	5.17	1.10	0.02	
10/11/86	4.00	4.40	5.07	4.40	1.07	0.00	
10/23/86	1.00	4.10	0.00	4.34	-1.00	0.24	
10/23/86	17.00	4.75	16.53	4.81	-0.47	0.06	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.

TB2-HIST.SW

Table 4.1-2 Comparison of Instantaneous Peak Stages, South Uvalda (continued)

Date	Historical Record Time (hrs)	Historical Record Peak Stage (ft)	Digitized Record Time (hrs)	Digitized Record Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
10/31/86	9.00	4.35	9.43	4.34	0.43	-0.01	
10/31/86	20.00	4.50	21.42	4.51	1.42	0.01	
11/01/86	3.00	4.45	3.65	4.44	0.65	-0.01	
11/07/86	3.00	4.75	3.33	4.72	0.33	-0.03	
11/30/86	17.00	4.05	17.90	4.08	0.90	0.03	
12/01/86	14.00	4.55	13.82	4.56	-0.18	0.01	
12/07/86	15.00	4.20	15.33	4.21	0.33	0.01	
04/01/87	21.00	4.25	22.66	4.22	1.66	-0.03	
04/02/87	10.00	4.25	11.35	4.21	1.35	-0.04	
04/12/87	12.00	4.70	12.86	4.79	0.86	0.09	
04/13/87	15.00	4.15	15.19	4.16	0.19	0.01	
04/20/87	7.00	4.55	7.79	4.48	0.79	-0.07	
05/01/87	17.00	4.80	15.90	5.16	-1.10	0.36	
05/02/87	18.00	4.60	17.07	4.72	-0.93	0.12	
05/02/87	22.00	5.05	22.04	5.16	0.04	0.11	
05/12/87	20.00	4.20	19.41	4.22	-0.59	0.02	
05/17/87	19.00	4.10	18.51	4.11	-0.49	0.01	
05/20/87	9.00	4.30	8.47	4.24	-0.53	-0.06	
05/20/87	23.00	4.85	21.81	4.43	-1.19	-0.42	
05/21/87	19.00	5.35	18.21	4.73	-0.79	-0.62	
05/30/87	21.00	4.45	21.46	4.05	0.46	-0.40	
06/09/87	1.00	5.75	0.00	3.92	-1.00	-1.83	
06/09/87	18.00	4.70	18.88	4.25	0.88	-0.45	
06/18/87	21.00	5.10	20.59	4.21	-0.41	0.89	
06/19/87	3.00	4.15	3.22	4.15	0.22	0.00	
06/28/87	20.00	4.20	19.21	4.14	-0.79	-0.06	
06/29/87	1.00	5.40	0.01	5.24	-0.99	-0.16	
06/29/87	18.00	7.70	18.90	4.84	0.90	-2.86	
07/12/87	9.00	4.75	8.52	4.80	-0.48	0.05	
07/24/87	1.00	5.40	0.00	5.24	-1.00	-0.16	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.

TB2-HIST.SW

Table 4.1-2 Comparison of Instantaneous Peak Stages, South Uvalda (continued)

Date	Historical Record		Digitized Record				
	Time (hrs)	Peak Stage (ft)	Time (hrs)	Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
07/29/87	18.00	4.30	18.92	4.35	0.92	0.05	
07/31/87	18.00	4.15	18.16	4.00	0.16	-0.15	
07/21/87	27.00	4.05	21.01	4.11	-5.99	0.06	
07/24/87	1.00	5.40	23.64	5.84	-1.36	0.44	Digitized peak on 07/23/87
07/25/87	22.00	4.05	19.61	4.35	-2.39	0.30	
07/26/87	22.00	4.05	21.33	4.21	-0.67	0.16	
09/14/87	24.00	5.05	21.75	5.90	-2.25	0.85	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.

TB2-HIST.SW

The difference between the magnitude and timing of 97 historically reduced instantaneous peaks versus the newly digitized instantaneous peaks is summarized in Table 4.1-3 (Comparison of Instantaneous Peak Stages). In general, the difference between the digitized record and the historical record was less than 1 hour. About 80 percent of the historical records showed timing of peak flows within 2 hours of the digitized records. The difference in peak stage was ± 0.05 ft or less for 53 percent of the peaks. However, only 66 percent of the peaks differed by ± 0.10 ft or less, and differences ranged to as much as 2.86 ft. This showed that significant errors occurred in the historical reduction of stage data, and that rounding the time of the peak to the nearest hour created a timing error for 20 percent of the values.

Ten randomly selected points from each month (except for periods of no record), showing the historical stage value along with the corresponding digitized stage value are listed in Table 4.1-4 (General Stage Comparison). For this analysis, the historical stage value was within ± 0.05 ft of the newly digitized stage value for 83 percent of the values, and within ± 0.10 ft for 92 percent of the values. This analysis included a high proportion of baseflow conditions, for which the historical and digitized values should be very close; this accounts for the relatively high agreement between these data sets.

The final step in the review included a comparison of the historical discharge records to newly computed discharge records based on digitized strip charts. This step included:

- comparison of the minimum and maximum monthly instantaneous stages and flows;
- comparison of the minimum and maximum daily mean flows; and
- comparison of the total monthly flows.

The differences between the instantaneous minimum and maximum stages and flows for each month of record are summarized in Table 4.1-5 (Comparison of the Monthly Instantaneous Minimum and Maximum Stages and Flows). About 84 percent of the instantaneous minimum stages were within ± 0.05 ft of each other, and about 62 percent of the instantaneous maximum stages were within ± 0.05 ft of each other. About 42 percent of the historical minimum discharge values were within 10 percent of the digitized minimum discharge values. About 95 percent of the historical maximum discharge values differed by more than 10 percent from the digitized maximum discharge values, and the difference ranged up to 214 percent. Again, values show greater agreement during low flows, and divergence at higher

Table 4.1-3 Comparison of Instantaneous Peak Stages, South Uvalda (Page 1 of 4)

Date	Historical Record Time (hrs)	Historical Record Peak Stage (ft)	Digitized Record Time (hrs)	Digitized Record Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
10/01/85	14.00	4.20	14.23	4.18	0.23	-0.02	
10/11/85	5.00	4.60	4.78	4.77	-0.22	0.17	
10/11/85	10.00	4.20	10.38	4.30	0.38	0.10	
10/13/85	13.00	4.25	12.80	4.28	-0.20	0.03	
10/13/85	21.00	4.65	21.69	4.68	0.69	0.03	
10/14/85	12.00	4.10	12.44	4.15	0.44	0.05	
10/31/85	17.00	5.00	17.70	5.06	0.70	0.06	
10/31/85	19.00	4.80	19.50	4.86	0.50	0.06	
11/09/85	9.00	4.65	9.57	4.73	0.57	0.08	
11/09/85	15.00	4.20	15.83	4.21	0.83	0.01	
11/10/85	14.00	4.10	13.90	4.13	-0.10	0.03	
11/11/85	14.00	4.25	13.92	4.27	-0.08	0.02	
11/15/85	12.00	4.70	12.06	4.73	0.06	0.03	
11/19/85	14.00	4.15	13.67	4.17	-0.33	0.02	
11/20/85	14.00	4.15	13.71	4.19	-0.29	0.04	
11/25/85	13.00	4.30	13.92	4.31	0.92	0.01	
12/15/85	16.00	4.05	16.41	4.08	0.41	0.03	
03/17/86	0.00	4.20	0.55	4.38	0.55	0.18	
03/17/86	12.00	4.75	12.19	4.82	0.19	0.07	
03/19/86	18.00	4.25	18.28	4.30	0.28	0.05	
03/20/86	10.00	4.25	23.84	4.21	-10.16	-0.04	Digitized Peak on 03/19/86
03/20/86	9.00	4.30	8.76	4.28	-0.24	-0.02	
04/02/86	19.00	5.50	19.60	5.87	0.60	0.37	
04/04/86	15.00	5.70	16.58	5.81	1.58	0.11	
04/05/86	11.00	5.15	12.08	5.19	1.08	0.04	
04/06/86	14.00	4.85	14.37	4.84	0.37	-0.01	
04/07/86	15.00	4.65	14.54	4.67	-0.46	0.02	
04/09/86	8.00	4.60	7.30	4.61	-0.70	0.01	
04/11/86	21.00	4.65	20.34	4.88	-0.66	0.23	
04/17/86	12.00	5.10	12.94	5.16	0.94	0.06	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.
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Table 4.1-3 Comparison of Instantaneous Peak Stages, South Uvalda (Page 2 of 4)

	Historical Record		Digitized Record				
Date	Time (hrs)	Peak Stage (ft)	Time (hrs)	Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
04/20/86	24.00	4.90	1.33	4.92	1.33	0.02	Digitized peak on 04/21/86
04/26/86	12.00	4.40	16.69	4.67	4.69	0.27	
05/08/86	3.00	4.30	2.16	4.45	-0.84	0.15	
05/08/86	15.00	4.85	15.96	4.88	0.96	0.03	
05/15/86	14.00	4.85	14.15	5.17	0.15	0.32	
05/16/86	3.00	4.95	3.94	5.05	0.94	0.10	
06/02/86	1.00	4.60	1.37	4.74	0.37	0.14	
06/02/86	7.00	4.35	7.57	4.31	0.57	-0.04	
06/08/86	18.00	4.60	18.84	4.72	0.84	0.12	
06/09/86	10.00	4.25	10.73	4.28	0.73	0.03	
06/10/86	7.00	5.15	8.08	5.20	1.08	0.05	
06/16/86	21.00	4.40	22.05	4.67	1.05	0.27	
07/05/86	20.00	4.70	20.01	4.83	0.01	0.13	
07/16/86	18.00	4.50	19.27	4.36	1.27	-0.14	
07/17/86	20.00	5.85	21.10	6.38	1.10	0.53	
07/20/86	20.00	4.95	20.76	5.01	0.76	0.06	
07/22/86	20.00	4.45	20.45	4.49	0.45	0.04	
08/02/86	20.00	6.25	21.35	6.60	1.35	0.35	
08/16/86	22.00	4.15	22.45	4.17	0.45	0.02	
08/22/86	21.00	4.80	21.71	4.83	0.71	0.03	
08/29/86	18.00	4.40	18.81	4.41	0.81	0.01	
09/07/86	24.00	4.35	23.83	4.39	-0.17	0.04	
09/24/86	14.00	4.10	14.42	4.13	0.42	0.03	
10/03/86	6.00	4.20	6.94	4.20	0.94	0.00	
10/03/86	23.00	4.35	23.93	4.34	0.93	-0.01	
10/09/86	1.00	4.35	1.92	4.35	0.92	0.00	
10/10/86	21.00	5.15	22.10	5.17	1.10	0.02	
10/11/86	4.00	4.40	5.07	4.40	1.07	0.00	
10/23/86	1.00	4.10	0.00	4.34	-1.00	0.24	
10/23/86	17.00	4.75	16.53	4.81	-0.47	0.06	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.
TB2-HIST.SW

Table 4.1-3 Comparison of Instantaneous Peak Stages, South Uvalda (Page 3 of 4)

	Historical Record		Digitized Record				
Date	Time (hrs)	Peak Stage (ft)	Time (hrs)	Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
10/31/86	9.00	4.35	9.43	4.34	0.43	-0.01	
10/31/86	20.00	4.50	21.42	4.51	1.42	0.01	
11/01/86	3.00	4.45	3.65	4.44	0.65	-0.01	
11/07/86	3.00	4.75	3.33	4.72	0.33	-0.03	
11/30/86	17.00	4.05	17.90	4.08	0.90	0.03	
12/01/86	14.00	4.55	13.82	4.56	-0.18	0.01	
12/07/86	15.00	4.20	15.33	4.21	0.33	0.01	
04/01/87	21.00	4.25	22.66	4.22	1.66	-0.03	
04/02/87	10.00	4.25	11.35	4.21	1.35	-0.04	
04/12/87	12.00	4.70	12.86	4.79	0.86	0.09	
04/13/87	15.00	4.15	15.19	4.16	0.19	0.01	
04/20/87	7.00	4.55	7.79	4.48	0.79	-0.07	
05/01/87	17.00	4.80	15.90	5.16	-1.10	0.36	
05/02/87	18.00	4.60	17.07	4.72	-0.93	0.12	
05/02/87	22.00	5.05	22.04	5.16	0.04	0.11	
05/12/87	20.00	4.20	19.41	4.22	-0.59	0.02	
05/17/87	19.00	4.10	18.51	4.11	-0.49	0.01	
05/20/87	9.00	4.30	8.47	4.24	-0.53	-0.06	
05/20/87	23.00	4.85	21.81	4.43	-1.19	-0.42	
05/21/87	19.00	5.35	18.21	4.73	-0.79	-0.62	
05/30/87	21.00	4.45	21.46	4.05	0.46	-0.40	
06/09/87	1.00	5.75	0.00	3.92	-1.00	-1.83	
06/09/87	18.00	4.70	18.88	4.25	0.88	-0.45	
06/18/87	21.00	5.10	20.59	4.21	-0.41	0.89	
06/19/87	3.00	4.15	3.22	4.15	0.22	0.00	
06/28/87	20.00	4.20	19.21	4.14	-0.79	-0.06	
06/29/87	1.00	5.40	0.01	5.24	-0.99	-0.16	
06/29/87	18.00	7.70	18.90	4.84	0.90	-2.86	
07/12/87	9.00	4.75	8.52	4.80	-0.48	0.05	
07/24/87	1.00	5.40	0.00	5.24	-1.00	-0.16	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.
TB2-HIST.SW

Table 4.1-3 Comparison of Instantaneous Peak Stages, South Uvalda (Page 4 of 4)

	Historical Record		Digitized Record				
Date	Time (hrs)	Peak Stage (ft)	Time (hrs)	Peak Stage (ft)	Time Difference (hrs)	Peak Stage Difference* (ft)	Comments
07/29/87	18.00	4.30	18.92	4.35	0.92	0.05	
07/31/87	18.00	4.15	18.16	4.00	0.16	-0.15	
07/21/87	27.00	4.05	21.01	4.11	-5.99	0.06	
07/24/87	1.00	5.40	23.64	5.84	-1.36	0.44	Digitized peak on 07/23/87
07/25/87	22.00	4.05	19.61	4.35	-2.39	0.30	
07/26/87	22.00	4.05	21.33	4.21	-0.67	0.16	
09/14/87	24.00	5.05	21.75	5.90	-2.25	0.85	

* Magnitude Difference = Digitized Peak Magnitude - Historical Peak Magnitude.

TB2-HIST.SW

Table 4.1-4 General Stage Comparison, South Uvalda (Page 1 of 4)

Date	Time (hrs)	Historical Stage (ft)	Digitized Stage (ft)	Difference* (ft)
10/02/85	2.00	4.00	3.97	-0.03
10/05/85	20.00	3.95	3.95	0.00
10/07/85	8.00	3.95	3.95	0.00
10/09/85	5.00	3.90	3.94	0.04
10/12/85	3.00	3.90	3.92	0.02
10/14/85	17.00	3.95	3.94	-0.01
10/19/85	23.00	3.90	3.93	0.03
10/24/85	20.00	3.95	3.93	-0.02
10/27/85	12.00	3.90	3.92	0.02
10/30/85	6.00	3.95	3.92	-0.03
11/01/85	10.00	3.95	3.94	-0.01
11/03/85	7.00	3.95	3.95	0.00
11/06/85	20.00	3.95	3.97	0.02
11/09/85	14.00	4.10	4.08	-0.02
11/13/85	15.00	4.00	4.01	0.01
11/16/85	22.00	3.95	3.93	-0.02
11/19/85	19.00	3.95	3.96	0.01
11/23/85	9.00	3.90	3.91	0.01
11/25/85	7.00	3.95	3.91	-0.04
11/29/85	4.00	3.90	3.94	0.04
12/01/85	13.00	3.90	3.94	0.04
12/04/85	14.00	3.95	3.95	0.00
12/07/85	19.00	3.95	3.92	-0.03
12/11/85	4.00	3.90	3.90	0.00
12/15/85	19.00	4.00	4.01	0.01
03/05/86	23.00	3.90	3.90	0.00
03/09/86	5.00	3.90	3.90	0.00
03/11/86	18.00	3.90	3.91	0.01
03/16/86	8.00	3.90	3.89	-0.01
03/17/86	12.00	4.75	4.44	-0.31
03/20/86	3.00	4.10	4.01	-0.09
03/21/86	2.00	3.90	3.88	-0.02
03/24/86	8.00	3.90	3.89	-0.01
03/28/86	16.00	3.95	3.98	0.03
03/31/86	5.00	3.90	3.91	0.01
04/01/86	17.00	3.90	3.90	0.00
04/03/86	18.00	3.90	3.88	-0.02
04/05/86	14.00	4.95	4.94	-0.01
04/08/86	12.00	4.35	4.30	-0.05
04/10/86	20.00	4.00	4.01	0.01
04/14/86	18.00	4.00	4.00	0.00
04/18/86	1.00	4.00	4.01	0.01
04/21/86	20.00	4.00	3.98	-0.02
04/25/86	1.00	4.00	3.99	-0.01
04/30/86	23.00	4.00	4.00	0.00
05/02/86	2.00	4.05	3.99	-0.06
05/05/86	11.00	4.00	4.02	0.02
05/08/86	19.00	4.15	4.14	-0.01
05/11/86	7.00	3.95	3.97	0.02
05/13/86	22.00	4.05	4.05	0.00
05/16/86	2.00	4.80	4.91	0.11

Table 4.1-4 General Stage Comparison, South Uvalda (Page 2 of 4)

Date	Time (hrs)	Historical Stage (ft)	Digitized Stage (ft)	Difference* (ft)
05/19/86	21.00	4.00	3.97	-0.03
05/22/86	2.00	3.95	4.03	0.08
05/26/86	4.00	4.00	4.07	0.07
05/28/86	15.00	4.00	4.02	0.02
06/04/86	5.00	3.95	3.99	0.04
06/07/86	8.00	3.95	3.95	0.00
06/10/86	10.00	4.55	4.80	0.25
06/11/86	22.00	4.00	3.99	-0.01
06/15/86	14.00	4.00	4.04	0.04
06/18/86	5.00	4.00	4.00	0.00
06/22/86	20.00	4.05	4.06	0.01
06/25/86	19.00	4.05	4.04	-0.01
06/27/86	12.00	4.00	4.01	0.01
06/30/86	9.00	4.00	3.98	-0.02
07/01/86	15.00	4.00	3.99	-0.01
07/05/86	21.00	4.45	4.59	0.14
07/09/86	5.00	3.95	3.97	0.02
07/11/86	23.00	4.05	4.04	-0.01
07/12/86	2.00	3.95	3.99	0.04
07/16/86	14.00	4.00	4.01	0.01
07/18/86	15.00	4.00	4.00	0.00
07/22/86	2.00	4.00	4.01	0.01
07/25/86	6.00	4.00	4.00	0.00
07/30/86	3.00	4.05	4.03	-0.02
08/02/86	20.00	6.25	4.17	-2.08
08/05/86	23.00	4.00	4.02	0.02
08/11/86	18.00	4.00	4.01	0.01
08/13/86	1.00	4.10	4.07	-0.03
08/16/86	15.00	3.95	3.97	0.02
08/19/86	18.00	4.00	3.98	-0.02
08/23/86	1.00	4.05	4.06	0.01
08/25/86	12.00	3.95	3.98	0.03
08/30/86	2.00	3.95	3.99	0.04
08/31/86	7.00	3.95	3.95	0.00
09/01/86	8.00	3.95	3.95	0.00
09/02/86	15.00	3.95	3.95	0.00
09/05/86	7.00	4.00	3.99	-0.01
09/09/86	22.00	3.95	3.93	-0.02
09/15/86	4.00	4.00	3.99	-0.01
09/16/86	13.00	3.95	3.92	-0.03
09/19/86	7.00	4.00	3.97	-0.03
09/24/86	14.00	4.10	4.11	0.01
09/25/86	12.00	3.95	3.96	0.01
09/29/86	4.00	4.00	4.07	0.07
10/01/86	6.00	4.05	4.06	0.01
10/02/86	19.00	4.00	3.98	-0.02
10/08/86	21.00	3.95	3.95	0.00
10/10/86	12.00	3.95	3.94	-0.01
10/11/86	6.00	4.20	4.33	0.13
10/21/86	15.00	3.95	3.94	-0.01

Table 4.1-4 General Stage Comparison, South Uvalda (Page 3 of 4)

Date	Time (hrs)	Historical Stage (ft)	Digitized Stage (ft)	Difference* (ft)
10/23/86	2.00	4.00	4.03	0.03
10/24/86	3.00	3.95	3.95	0.00
10/29/86	8.00	3.95	3.94	-0.01
10/31/86	22.00	4.35	4.43	0.08
11/01/86	1.00	4.30	4.34	0.04
11/02/86	14.00	4.00	3.98	-0.02
11/03/86	17.00	3.95	3.92	-0.03
11/07/86	18.00	3.95	3.93	-0.02
11/12/86	4.00	3.90	3.89	-0.01
11/16/86	11.00	3.90	3.89	-0.01
11/17/86	3.00	3.85	3.88	0.03
11/19/86	7.00	3.85	3.88	0.03
11/23/86	20.00	3.85	3.88	0.03
11/30/86	9.00	3.90	3.90	0.00
12/01/86	11.00	3.90	3.92	0.02
12/02/86	21.00	3.90	4.02	0.12
12/05/86	17.00	3.95	3.93	-0.02
12/07/86	14.00	4.15	4.13	-0.02
04/02/87	1.00	4.05	4.05	0.00
04/02/87	3.00	3.95	4.00	0.05
04/04/87	15.00	3.90	3.87	-0.03
04/11/87	15.00	3.90	3.96	0.06
04/18/87	2.00	3.95	4.10	0.15
04/20/87	8.00	4.30	4.48	0.18
04/21/87	20.00	3.90	3.90	0.00
04/23/87	12.00	3.90	3.90	0.00
04/27/87	15.00	3.90	3.88	-0.02
04/29/87	17.00	3.95	3.94	-0.01
05/01/87	13.00	3.95	3.97	0.02
05/02/87	20.00	4.50	4.52	0.02
05/03/87	9.00	4.00	3.98	-0.02
05/09/87	13.00	3.90	3.90	0.00
05/16/87	9.00	3.95	3.95	0.00
05/18/87	3.00	3.95	3.99	0.04
05/20/87	11.00	4.20	4.10	-0.10
05/21/87	18.00	5.00	4.73	-0.27
05/26/87	11.00	3.90	3.92	0.02
05/31/87	9.00	4.00	3.97	-0.03
06/06/87	6.00	3.80	3.90	0.10
06/08/87	7.00	3.95	3.95	0.00
06/10/87	12.00	3.95	3.94	-0.01
06/12/87	9.00	3.95	3.98	0.03
06/14/87	13.00	3.90	3.96	0.06
06/18/87	19.00	4.35	4.20	-0.15
06/25/87	13.00	3.95	3.94	-0.01
06/29/87	1.00	5.40	4.95	-0.45
06/29/87	8.00	4.15	4.04	-0.11
06/30/87	16.00	3.90	3.95	0.05
07/02/87	16.00	3.90	3.94	0.04
07/04/87	22.00	3.90	3.98	0.08

Table 4.1-4 General Stage Comparison, South Uvalda (Page 4 of 4)

Date	Time (hrs)	Historical Stage (ft)	Digitized Stage (ft)	Difference* (ft)
07/08/87	4.00	3.90	4.05	0.15
07/09/87	22.00	4.00	4.08	0.08
07/10/87	15.00	4.00	4.03	0.03
07/14/87	10.00	3.95	3.96	0.01
07/15/87	3.00	4.00	4.00	0.00
07/17/87	9.00	3.95	3.99	0.04
07/20/87	18.00	3.95	3.99	0.04
07/23/87	19.00	4.00	4.04	0.04
08/05/87	16.00	4.05	4.00	-0.05
08/06/87	21.00	4.00	4.02	0.02
08/08/87	4.00	4.00	4.09	0.09
08/12/87	14.00	4.10	4.04	-0.06
08/16/87	8.00	4.00	3.99	-0.01
08/21/87	20.00	4.00	4.09	0.09
08/25/87	20.00	4.20	4.34	0.14
08/26/87	4.00	4.20	4.16	-0.04
08/27/87	7.00	4.05	4.04	-0.01
08/31/87	23.00	4.00	4.00	0.00
09/04/87	1.00	4.00	4.02	0.02
09/08/87	16.00	4.00	4.00	0.00
09/10/87	13.00	4.00	4.01	0.01
09/10/87	16.00	4.00	4.00	0.00
09/12/87	9.00	4.00	4.02	0.02
09/14/87	7.00	4.05	4.04	-0.01
09/22/87	10.00	4.00	4.01	0.01
09/23/87	16.00	4.00	4.00	0.00
09/25/87	11.00	4.00	4.01	0.01
09/29/87	6.00	4.00	4.02	0.02

* Difference = Digitized Stage - Historical Stage.

Table 4.1-5 Comparison of the Monthly Instantaneous Minimum and Maximum Stages and Flows, South Uvalda

	Historical Record[1]				Digitized Record				Differences in Historical vs Digitized Record			
	Stage (ft)		Discharge (cfs)		Stage (ft)		Discharge (cfs)		Difference in stage (ft)		% Difference in discharge (cfs)	
Month	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Oct 85	3.90	5.08	0.40	42.0	3.90	5.06	0.37	22.74	0.00	-0.02	-8.11	-84.70
Nov 85	3.89	4.78	0.40	8.4	3.90	4.73	0.37	5.48	0.01	-0.05	-8.11	-53.28
Dec 85	3.89	4.08	0.40	1.2	3.89	4.08	0.35	0.99	0.00	0.00	-14.29	-21.21
Mar 86	3.90	4.82	0.40	8.4	3.88	4.82	0.34	6.11	-0.02	0.00	-17.65	-37.48
Apr 86	3.76	5.86	0.20	121.0	3.76	5.87	0.16	48.54	0.00	0.01	-25.00	-149.28
May 86	3.91	5.22	0.40	52.0	3.94	5.17	0.47	27.16	0.03	-0.05	14.89	-91.46
Jun 86	3.94	4.78	0.50	8.4	3.93	5.20	0.44	27.89	-0.01	0.42	-13.64	69.88
Jul 86	3.88	6.42	0.40	181.0	3.93	6.38	0.44	71.04	0.05	-0.04	9.09	-154.79
Aug 86	3.90	6.62	0.40	202.0	3.92	6.60	0.42	82.95	0.02	-0.02	4.76	-143.52
Sep 86	3.91	4.37	0.40	2.8	3.90	4.39	0.37	3.56	-0.01	0.02	-8.11	21.35
Oct 86	3.90	5.22	0.40	52.0	3.88	5.17	0.34	27.16	-0.02	-0.05	-17.65	-91.46
Nov 86	3.85	4.75	0.30	7.6	3.86	4.72	0.30	5.41	0.01	-0.03	0.00	-40.48
Dec 86	3.87	4.56	0.30	4.7	3.86	4.56	0.30	4.44	-0.01	0.00	0.00	-5.86
Apr 87	0.00	4.72	0.00	6.8	3.84	4.79	0.27	5.89	3.84	0.07	100.00	-15.45
May 87	3.88	5.35	0.40	67.0	3.86	5.16	0.30	26.92	-0.02	-0.19	-33.33	-148.89
Jun 87	3.85	5.90	0.30	128.0	3.85	5.65	0.28	40.76	0.00	-0.25	-7.14	-214.03
Jul 87	3.85	5.81	0.30	118.0	3.92	5.84	0.42	47.42	0.07	0.03	28.57	-148.84
Aug 87	3.00	5.00	0.00	31.0	3.97	5.69	0.55	42.10	0.97	0.69	100.00	26.37
Sep 87	3.80	5.75	0.20	110.0	3.99	5.90	0.61	49.65	0.19	0.15	67.21	-121.55

* Stage difference = Digitized Record - Historic Record

** Discharge difference = ((Digitized Record - Historic Record)/Digitized Record) X 100

1 Data reported in WRI Report (Ebasco 1989a; Appendix B).

flows. Significant departures occurred in historical reductions for monthly instantaneous maximum stage. Values for both minimum and maximum instantaneous discharges contained significant errors when compared to digitized discharges.

Differences between the historical and digitized values of minimum and maximum daily mean flows for each month of record are summarized in Table 4.1-6 (Comparison of the Minimum and Maximum Daily Mean Flows). This comparison also revealed substantial differences between the historical and newly digitized records. For the minimum daily mean flows, the historical and digitized values differed by more than 10 percent about 31 percent of the time. For the maximum daily mean flows, the historical values differed from digitized values by more than 10 percent about 79 percent of the time. Historical maximums were as much as 217 percent higher than digitized values. This shows that for both minimum and maximum daily mean flows, the historically reduced values differed significantly from the more precise digitized values.

Comparison of total monthly flow volumes (Table 4.1-7) demonstrates that, in general, the historical total monthly flows are higher than the digitized values. The historical total monthly flow differed by more than 10 percent from the digitized total monthly flow on about 68 percent of the values. The historical flow value exceeded the digitized flow value by a maximum of 119 percent. Again, this shows that historical stage data reduction created inaccuracies in discharge data.

When both low flow and peak flow records were included, the stage record was relatively close to the historical record. This is due to the high proportion of low flow values, which logically should be in close agreement. However, based on the stage comparisons, it is evident that the historical instantaneous peak stages were frequently in error. The historical discharge record was consistently higher than the digitized discharge record. This was mainly due to the differences between the stage records and between the historical rating curve and the newly revised rating curve used to produce the new discharge records. In summary, the historical strip charts for South Uvalda were not accurately reduced, nor were the resulting stage records accurately converted to discharge records. Since the methods used to reduce South Uvalda gaging records were historically similar for all other stations, the credibility of historically reduced strip charts, stage and discharge records for all RMA continuous-recording gaging stations is in question.

Table 4.1-6 Comparison of the Minimum and Maximum Daily Mean Flows, South Uvalda

Month	Historic Discharge+ Record Min	Historic Discharge+ Record Max	Digitized Discharge Record Min	Digitized Discharge Record Max	Percent Difference Historical vs Digitized Discharge Record Min	Percent Difference Historical vs Digitized Discharge Record Max
Oct 85	0.40	2.8	0.39	2.0	-2.56%	-40.00%
Nov 85	0.40	1.5	0.38	1.5	-5.26%	0.00%
Dec 85	0.40	0.6	0.37	0.52	-8.11%	-15.38%
Mar 86	0.40	1.3	0.36	1.2	-11.11%	-8.33%
Apr 86	0.40	25.8	0.361	3.0	-11.11%	-98.46%
May 86	0.60	5.3	0.56	4.8	-7.14%	-10.42%
Jun 86	0.60	6.0	0.58	3.6	-3.45%	-66.67%
Jul 86	0.50	8.3	0.47	4.0	-6.38%	-107.50%
Aug 86	0.50	14.9	0.53	7.6	5.66%	-96.05%
Sep 86	0.40	0.8	0.42	0.8	4.76%	0.00%
Oct 86	0.40	3.5	0.39	2.4	-2.56%	-45.83%
Nov 86	0.30	1.6	0.31	1.9	3.23%	15.79%
Dec 86	0.30	1.1	0.31	1.1	3.23%	0.00%
Apr 87	0.30	2.5	0.32	2.8	6.25%	10.71%
May 87	0.40	11.1	0.33	3.5	-21.21%	-217.14%
Jun 87	0.20	9.4	0.30	4.7	33.33%	-100.00%
Jul 87	0.40	4.5	0.49	2.5	18.37%	-80.00%
Aug 87	0.60	38.3	0.63	22.0	4.76%	-74.09%
Sep 87	0.30	5.7	0.66	4.9	54.55%	-16.33%

* % Difference = ((Digitized Total - Historic Total)/Digitized Total) X 100
\+ Discharge records reported in WRI Report (Ebasco, 1989a)

Table 4.1-7 Comparison of Total Monthly Flows, South Uvalda

Month	Historical Total Monthly Flow+ (ac-ft)	Digitized Total Monthly Flow (ac-ft)	Percent Difference*
Oct 85	37.40	34.83	-7.38%
Nov 85	34.20	31.93	-7.11%
Dec 85**	14.90	13.60	-9.56%
Mar 86**	28.20	25.18	-11.99%
Apr 86	147.20	103.66	-42.00%
May 86	56.80	65.59	13.40%
Jun 86	58.30	48.46	-20.31%
Jul 86	73.30	57.86	-26.69%
Aug 86	75.40	64.72	-16.50%
Sep 86	34.80	32.51	-7.04%
Oct 86	49.00	44.11	-11.09%
Nov 86	27.10	26.14	-3.67%
Dec 86**	7.70	9.20	16.30%
Apr 87	33.90	9.05	13.19%
May 8	94.80	48.93	-93.75%
Jun 87	90.30	41.24	-118.96%
Jul 87	48.90	49.88	1.96%
Aug 87	134.40	91.24	-47.30%
Sep 87	61.80	54.92	-12.53%

* % Difference = ({Digitized Total - Historic Total}/Digitized Total) X 100
** Based on partial records for the month.
\+ Based on Daily Discharge summary sheets (RCI, unpublished 1987).

4.1.2 LAKE AND POND STAGE DATA

Historical records regarding RMA surface-water body volume calculations are limited. During the period when Shell Chemical Co. had operations in the South Plants area, lake volume records were kept for Upper Derby, Lower Derby, and Ladora Lakes. This information for the years 1978 and 1979 is presented by RCI in Appendix A of a 1982 report, Surface-Water Hydrologic Analysis, Rocky Mountain Arsenal Denver, Colorado (RCI, 1982). This report contained monthly gage height values and accompanying water volumes for each of the three lakes (Table 4.1-8 and Table 4.1-9). It was not documented how often the lake staff gage values were recorded or if the monthly staff value represented an averaged or end-of-month value. RCI used this data to construct stage-volume curves for the lakes. This information was used with reported net inflow and net outflow data to calculate a water balance for the lakes. The difference between the calculated lake storage and the actual (measured) lake storage was then used to infer groundwater/surface-water interactions in the area.

In the succeeding report presented by RCI (1983), lake volumes were reported monthly for January through October 1982 (Table 4.1-10). A monthly staff gage reading and calculated lake volume were given. As in the previous report, it was not documented how the monthly staff gage values or monthly lake volumes were derived. It was reported that the previously developed stage-storage volume curves were used. Lower Derby Lake and Ladora Lake staff gage readings were obtained from RMA records (RCI, 1983).

In RCI's 1986 Annual Surface-Water Data Report, weekly lake stage values were reported for October 1, 1985 through September 9, 1986 for Upper Derby Lake, Lower Derby Lake, Ladora Lake, Lake Mary, and Havana Pond. It was reported that existing staff gages on Upper Derby, Lower Derby, and Ladora Lakes had a precision of 0.01 ft. The nearest weekly (Monday) staff gage reading to the first day of the month was used in monthly lake volume computations (RCI, 1986a). The conversion from lake stages to volumes in this report was accomplished using "adjusted stage-volume curves." These curves originated from an analysis and revision of older stage-volume curves for Upper Derby, Lower Derby, and Ladora Lakes. Documentation regarding the creation of the revised stage-volume curves was provided in a report by RCI, entitled Review and Proposed Revision of Stage Volume Curves for Rocky Mountain Arsenal's Lower Lakes (RCI, 1986b). These adjusted stage-volume curves were presented in tables showing lake volumes in acre-feet and lake area in acres. Lake volume and area were determined for every 0.1 ft increment of the staff gage. At the time of the report, Havana Pond had

Table 4.1-8 Shell Chemical Company Lake Water Inventory Data 1978

	INVENTORY IN LAKES					
	Upper Derby		Lower Derby		Ladora	
Month	(gage,ft)	(acre-ft)	(gage,ft)	(acre-ft)	(gage,ft)	(acre-ft)
January			13.20	355.9	12.0	351.9
February			13.00	341.4	12.0	351.9
March			12.40	306.1	11.95	349.2
April			11.05	210.7	12.1	357.1
May	3.3	61.5	14.50	446.4	12.0	357.1
June	9.75	386.1	19.55	849.9	12.2	362.3
July	6.2	177.1	19.0	804.8	12.2	362.3
August			18.40	753.8	12.1	357.1
September			16.15	559.9	11.95	349.2
October			14.8	355.4	12.1	357.1
November			14.1	420.4	12.1	357.1
December			14.0	413.6	12.0	351.9

Table 4.1-9 Shell Chemical Company Lake Water Inventory Data 1979

	INVENTORY IN LAKES					
	Upper Derby		Lower Derby		Ladora	
Month	(gage, ft)	(acre-ft)	(gage, ft)	(acre-ft)	(gage, ft)	(acre-ft)
January			13.3	363.1	12.1	357.1
February			13.0	341.4	12.0	351.9
March			13.2	355.9	12.1	357.1
April	6.5	189.4	18.8	797.8	12.1	357.1
May	10.10	489.7	19.6	853.9	12.1	357.1
June	7.4	231.9	19.5	845.8	11.9	346.5
July	3.9	80.4	18.1	728.3	12.05	354.5
August	7.2	220.9	19.2	821.1	12.1	357.1
September	4.9	120.1	18.9	796.3	12.1	357.1
October	4.5	104.5	17.8	702.6	12.05	354.5
November	4.0	84.9	17.3	659.6	12.15	359.7
December						

Table 4.1-10 Rocky Mountain Arsenal Water Data Inventory, January-October 1982

Month	Upper Derby (gage,ft) (acre-ft)	Lower Derby (gage,ft)	Lower Derby (acre-ft)[1]	Ladora (gage,ft)[1]	Ladora (acre-ft)[1]
January	Lake Empty	8.7	119.7	11.95	349.2
February	"	7.5	89.2	12.05	354.5
March	"	m	m	12.05	354.5
April	"	m	m	11.30	314.9e
May	"	10.2	193.3	11.95	349.2
June	"	15.6	519.2	12.10	357.1
July	"	14.25	431.3	12.05	354.5
August	"	13.40	370.8	12.05	354.5
September	"	12.00	273.9	12.00	351.9
October	"	11.25	222.6	12.00	351.9

m - missing data
1 - Volume in lakes is computed using data from 1978-79 stage volume data (RMA).

recently been surveyed by RCI. A stage-volume and stage-area relationship table similar in format to the tables for the other lakes was provided for Havana Pond. No stage-volume relationship was available for Lake Mary. Monthly lake volumes for WY86 (Table 4.1-11) were presented in a table which also contained volume gains and losses during the month. This data were then used for monthly water balance calculations.

The WRI Report (Ebasco, et al, 1989) presented stage-volume data for the South Plants lakes and Havana Pond for each month from October 1985 to October 1987 (Table 4.1-12). Stage-volume and stage-area relationship tables were presented for Upper Derby, Lower Derby, and Ladora Lakes, and Havana Pond. The relationships presented in these tables do not agree with the stage-volume and stage-area relationships presented by RCI (1986a). The tables in the WRI Report were created by using the original stage-volume and stage-area curves developed by Whitman et al. (1943). Lake volume data presented in the WRI Report were used to prepare water balance calculations. Because different stage-volume relationships were used by these two contractors, the lake volume data presented for the same period are different.

4.1.3 Evaporation and Precipitation Data

Precipitation data used by RCI in the water balance calculation for June through September 1982 was applied as a monthly total and converted to millions of gallons added to Lower Derby and Ladora Lake (RCI, 1983). The total area of both lakes was assumed to be 77.6 acres. Water entering the lakes as precipitation ranged from a low of 0.19 million gallons in February 1982 to a high of 7.33 million gallons in May of 1982 (Table 4.1-13). Evaporation data were not calculated for this period.

The WY86 RCI (1986a) used precipitation and evaporation data in water balance calculations for five of the surface-water bodies being monitored as part of the CMP (Table 4.1-13). Precipitation for all surface-water bodies was generally greatest in April and July. Evaporation from water bodies was greatest in July.

Precipitation to the five surface-water bodies for WY87 (Ebasco, et al, 1989a) was greatest in May and June and least in January. Evaporation from the lakes and Havana Pond was greatest in June and July and least in January (Table 4.1-13).

Table 4.1-11 RCI Water Year 1986 Lake Volume Calculations

Month	Upper and Lower Derby Lake Volume	Ladora Lake Volume	Havana Pond Volume
October 1985	622.3	345.8	40.5
November 1985	576.1	377.0	23.1
December 1985	572.2	389.8	9.0
January 1986	551.0	383.4	10.7
February 1986	533.4	389.8	4.3
March 1986	507.4	383.4	4.3
April 1986	489.5	383.4	4.3
May 1986	560.4	383.4	17.3
June 1986	537.9	377.0	14.6
July 1986	489.3	352.0	15.6
August 1986	559.2	333.7	23.1
September 1986	569.0	327.7	19.2

Note: All units in ac-ft.

Table 4.1-12 Water Remedial Investigation Water Year 1986 and Water Year 1987 Lake Volume Calculations

Month	Upper and Lower Derby Lake Volume	Ladora Lake Volume	Havana Pond Volume
October 1985	662.8	335.3	40.5
November 1985	615.4	366.3	22.4
December 1985	602.2	379.3	6.2
January 1986	578.0	372.8	4.3
February 1986	559.3	379.3	4.3
March 1986	538.9	379.3	4.3
April 1986	579.9	372.8	4.3
May 1986	586.7	372.8	8.6
June 1986	555.7	366.3	15.0
July 1986	510.8	341.1	15.3
August 1986	587.9	323.9	23.4
September 1986	495.9	318.1	19.2
October 1986	540.7	338.2	15.1
November 1986	510.8	341.1	38.6
December 1986	480.9	359.8	11.8
January 1987	460.1	366.3	6.5
February 1987	439.4	366.3	9.6
March 1987	432.5	372.8	14.3
April 1987	425.5	372.8	15.3
May 1987	425.5	366.3	17.3
June 1987	439.4	366.3	44.4
July 1987	628.2	372.8	68.2
August 1987	563.8	346.8	30.9
September 1987	548.2	329.6	36.2
October 1987	503.3	323.9	21.1
November 1987	460.1	329.6	33.5

Note: All units in ac-ft.

Table 4.1-13 Historical Precipitation and Evaporation Values Applied in Water Balance Calculations (Page 1 of 3)

Month/Year	Report	Precipitation on/ Evaporation from Lower Derby and Ladora (millions of gallons)	Precipitation on/ Evaporation from Upper and Lower Derby (ac-ft)	Precipitation on/ Evaporation from Ladora Lake (ac-ft)	Precipitation on/ Evaporation from Havana Pond (ac-ft)	Precipitation on Evaporation from Lake Mary (ac-ft)
1982	(RCI, 1983)					
January		0.67/NA				
February		0.19/NA				
March		0.38/NA				
April		0.72/NA				
May		7.33/NA				
June		4.76/NA				
July		1.94/NA				
August		2.44/NA				
September		2.91/NA				
October		3.18/NA				
TOTAL		24.45				
10-Month Average		2.45				
1985	(RCI, 1986)					
October			6.4/21.3	4.4/14.8	1.2/3.9	0.6/1.9
November			5.9/12.5	4.4/9.3	0.7/1.6	0.6/1.2
December			3.3/4.6	2.5/3.5	0.3/0.5	0.3/0.4
1986						
January			1.1/3.5	0.9/2.7	0.1/0.3	0.1/0.3
February			3.8/3.5	0.9/2.7	0.2/0.3	0.4/0.4

NA = Not analyzed

Table 4.1-13 Historical Precipitation and Evaporation Values Applied in Water Balance Calculations (Page 2 of 3)

Month/Year	Report	Precipitation on/ Evaporation from Lower Derby and Ladora (millions of gallons)	Precipitation on/ Evaporation from Upper and Lower Derby (ac-ft)	Precipitation on/ Evaporation from Ladora Lake (ac-ft)	Precipitation on/ Evaporation from Havana Pond (ac-ft)	Precipitation on Evaporation from Lake Mary (ac-ft)
March			3.0/7.6	2.4/6.2	0.2/0.5	0.3/0.8
April			11.7/15.4	9.5/12.4	1.2/1.6	1.2/1.6
May			8.7/32.6	7.2/27.1	1.3/4.7	0.9/3.5
June			6.7/41.2	6.0/37.0	1.0/6.4	0.8/4.8
July			9.0/50.4	7.8/43.7	1.6/8.9	1.0/5.8
August			4.8/34.6	4.1/29.8	0.9/6.6	0.6/4.0
September			2.9/29.1	2.5/25.6	0.5/4.9	0.3/3.4
TOTAL			67.3/257.2	54.7/215.6	9.2/40.2	7.1/28.1
12-Month Average			5.61/21.43	4.56/17.97	0.77/3.35	0.59/2.34
	(Ebasco, 1989a)					
October			7.5/17.5	5.7/13.2	1.4/3.3	0.8/1.8
November			5.2/11.5	4.4/9.7	1.0/2.2	0.6/1.3
December			1.0/3.7	0.8/3.3	0.1/0.4	0.1/0.4
1987						
January			2.2/2.8	2.0/2.6	0.2/0.3	0.3/0.3
February			4.7/3.6	4.4/3.3	0.7/0.5	0.6/0.4
March			5.4/6.3	5.1/6.0	0.9/1.0	0.7/0.8
April			4.2/12.6	3.9/11.9	0.7/2.1	0.5/1.5
May			23.4/19.8	21.8/18.5	5.5/4.6	2.8/2.4
June			19.8/45.6	15.5/36.7	5.6/13.0	2.0/4.5
July			5.8/49.0	4.2/35.4	1.4/12.1	0.5/4.6

NA - Not Analyzed

TB2-HIST.SW

Table 4.1-13 Historical Precipitation and Evaporation Values Applied in Water Balance Calculations (Page 3 of 3)

Month/Year	Report	Precipitation on/ Evaporation from Lower Derby and Ladora (millions of gallons)	Precipitation on/ Evaporation from Upper and Lower Derby (ac-ft)	Precipitation on/ Evaporation from Ladora Lake (ac-ft)	Precipitation on/ Evaporation from Havana Pond (ac-ft)	Precipitation on Evaporation from Lake Mary (ac-ft)
August			10.5/36.4	8.0/27.9	2.3/8.1	0.3/4.2
September			3.0/39.0	2.3/30.2	0.6/8.1	0.3/4.2
TOTAL			92.7/247.8	78.7/198.7	20.4/55.7	10.3/26.0
12-Month Average			7.73/20.65	6.56/16.56	1.7/4.64	0.86/2.17
October			6.2/21.6	5.0/17.5	1.3/4.6	0.7/2.4
November			7.0/11.0	6.0/9.4	1.6/2.5	0.8/1.3

NA - Not Analyzed

TB2-HIST.SW

4.1.4 Sewage Treatment Plant Discharge Data

Historical discharge data are available for the Sewage Treatment Plant for WY86 and WY87 (Ebasco, et al, 1989a). Records show a total discharge flow of 3,743,200 gal in WY86 and 3,606,000 gallons in WY87. Daily average flows were approximately the same for both water years (Table 4.1-14).

4.2 CMP Surface-Water Quantity Data Assessment

Surface-water quantity data and results obtained during WY89 of the CMP are discussed in the following sections. Significant differences from previous years, apparent trends, anomalies, etc., are identified.

4.2.1 Stream Flow Data

Items of interest in a streamflow monitoring program include relative flow rates and volumes as well as variability of flow. Table 4.2-1 presents all documented flow data collected at RMA gaging stations from WY82 through WY89. Estimated flow values for December, January, February, and March for WY83, WY86, and WY87 are presented on Table 4.1-1. No discharge records are available for WY84 or WY85.

Minimum daily mean flow, maximum daily mean flow, the number of days each month that flow was analyzed (days of record) and total monthly flow are provided on Table 4.2-1. This table can be used to compare pre-CMP (WY82 through WY87) to CMP (WY88 and WY89) discharge values. Consideration of those deficiencies and limitations noted in the pre-CMP discharge data, as discussed in Sections 4.1.1 - 4.1.1.1.1, should be applied while reviewing historical trends.

4.2.1.1 Rates and Volumes of Flow

The stations that had the largest rates and volumes of flow during WY89 were those measuring inflow to RMA (South Uvalda, Peoria Interceptor, Havana Interceptor, Highline Lateral and South First Creek), totaling 1,980 ac-ft for April through September. This is consistent with previous years (Table 4.2-1). The Irondale Gulch drainage basin produced about 60 percent of the total inflow onto RMA during WY89. Unit runoff values have been calculated for April through August for these gaging stations (Table 4.2-2). Unit runoff is equal to the volume of flow for this period divided by the drainage basin area.

Table 4.1-14 Sewage Treatment Plant Monthly Flow Summaries, Water Year 1986 and 1987

Month	Monthly Total (gallons)	Daily Average (gpd)	Daily Average (gpm)
WY86			
October	387,400	12,497	8.68
November	309,500	10,317	7.16
December	206,000	6,645	4.61
January	188,400	6,077	4.22
February	95,000	3,393	2.36
March	164,600	5,310	3.69
April	447,700	14,923	10.36
May	602,300	19,429	13.49
June	507,100	16,903	11.74
July	386,700	12,474	8.66
August	266,100	8,584	5.96
September	182,400	6,080	4.22
AVERAGE	311,933	10,219	7.09
TOTAL FOR YEAR	3,743,200		
WY87			
October	297,200	9,587	6.66
November	446,400	14,880	10.33
December	534,300	17,235	11.97
January	240,400	7,755	5.36
February	205,300	7,332	5.09
March	309,500	9,984	6.93
April	400,400	13,347	9.27
May	338,000	10,903	7.57
June	128,400	4,280	2.97
July	327,600	10,567	7.34
August	387,200	12,490	8.67
September	295,500	9,850	6.84
AVERAGE	300,500	10,684	7.42
TOTAL FOR YEAR	3,606,000		

gpd - gallons per day
gpm - gallons per minute

TABLE 4.2-1 (Page 1 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

BASIN A		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		19			31	31	31	31
	Total (ac-ft)		0.46			0.58	0.79	0.24	TR
	Min (cfs)		T			0.01	0.00	T	TR
	Max (cfs)		0.15			0.02	0.06	0.05	TR
NOVEMBER	Days of Record		18			30	30	30	30
	Total (ac-ft)		0.10			0.56	0.67	0.20	TR
	Min (cfs)		T			0.00	0.00	TR	TR
	Max (cfs)		0.05			0.03	0.09	0.03	TR
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	21
	Total (ac-ft)								TR
	Min (cfs)								TR
	Max (cfs)								TR
APRIL	Days of Record	1	30			30	30	27	20
	Total (ac-ft)	0.00	0.97			4.31	0.42	0.24	TR
	Min (cfs)	0.00	T			0.00	0.00	TR	TR
	Max (cfs)	0.00	0.27			0.46	0.05	0.02	TR
MAY	Days of Record	11	29			31	31	30	31
	Total (ac-ft)	0.00	2.80			1.04	2.19	2.72	0.46
	Min (cfs)	0.00	T			0.01	0.10	TR	TR
	Max (cfs)	0.15	0.67			0.13	0.33	0.67	0.09
JUNE	Days of Record		29			30	30	30	29
	Total (ac-ft)		1.01			0.91	1.68	0.16	0.67
	Min (cfs)		T			0.01	0.01	TR	TR
	Max (cfs)		0.36			0.12	0.22	0.05	0.12
JULY	Days of Record		31			31	31	31	31
	Total (ac-ft)		0.85			0.77	0.69	0.02	0.14
	Min (cfs)		T			0.00	0.01	TR	TR
	Max (cfs)		0.34			0.11	0.04	0.01	0.05
AUGUST	Days of Record	29	28			31	31	31	31
	Total (ac-ft)	0.47	0.31			0.84	1.06	TR	TR
	Min (cfs)	0.00	T			0.00	0.00	0.01	TR
	Max (cfs)	0.16	0.13			0.21	0.22	0.01	TR
SEPTEMBER	Days of Record	30	28			30	30	30	30
	Total (ac-ft)	0.45	0.11			0.19	2.30	0.02	0.06
	Min (cfs)	0.00	T			0.00	0.00	TR	TR
	Max (cfs)	0.12	0.06			0.02	0.14	0.01	0.01

T = Trace Flow; NR = Not Recorded; TR = Trace (Flow greater than 0.00 cfs but less than 0.005 cfs)
E = Estimated daily flow values recorded during this month

TABLE 4.2-1 (Page 2 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

HIGHLINE LATERAL		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		31			31	31	31	31
	Total (ac-ft)		0.00			0.00	0.00	0.00	194.34
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			0.00	0.00	0.00	21.00
NOVEMBER	Days of Record		30			30	30	30	14
	Total (ac-ft)		0.00			0.00	0.00	0.00	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			0.00	0.00	0.00	0.00
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
APRIL	Days of Record		30			30	30	27	20
	Total (ac-ft)		0.00			0.00	0.00	0.00	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			0.00	0.00	0.00	0.00
MAY	Days of Record		31			31	31	29	31
	Total (ac-ft)		91.84			0.00	0.00	480.58	378.05
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		14.93			0.00	0.00	19.00	22.00
JUNE	Days of Record		30			30	30	30	29
	Total (ac-ft)		0.00			0.00	262.60	24.73	54.74
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			0.00	11.80	19.00	18.00
JULY	Days of Record		31			31	31	31	7
	Total (ac-ft)		0.00			145.10	148.40	376.07	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			13.50	11.30	11.00	0.00
AUGUST	Days of Record		31			31	31	31	9
	Total (ac-ft)		0.00			0.00	51.10	371.07	28.20
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			0.00	7.90	21.00	7.20
SEPTEMBER	Days of Record		30			30	30	30	30
	Total (ac-ft)		0.00			162.70	0.00	338.18	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		0.00			12.50	0.00	20.0	0.00

E = Estimated daily flow values recorded during this month; NR = Not Recorded

TABLE 4.2-1 (Page 3 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

PEORIA INTERCEPTOR		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 6.90 0.00 1.10	31 12.90 0.00 0.00	31 14.76 0.00 3.20	31 23.96 0.00 0.95
NOVEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 3.40 0.00 0.60	30 7.40 0.00 1.30	30 21.64 0.00 2.20	29 11.19 0.00 2.40
DECEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
JANUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
FEBRUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	1 0.22 0.11 0.11
MARCH	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	31 22.10 0.00 1.20
APRIL	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 26.20 0.00 3.30	30 9.00 0.00 1.50	30 9.69 0.00 2.10	20 21.26 0.02 3.80
MAY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 10.40 0.00 2.90	31 37.80 0.00 5.60	31 82.08 0.00 15.00	26 61.69 0.05 6.00
JUNE	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 7.30 0.00 1.60	30 13.00 0.00 2.00	30 27.13 0.00 2.70	23 72.20 0.07 18.60
JULY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 17.00 0.00 4.90	31 19.20 0.00 4.90	28 53.99 0.11 3.60	29 35.59 0.13 8.70
AUGUST	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 14.60 0.00 4.80	31 40.90 0.00 7.60	31 46.67 0.00 3.10	30 22.37 0.05 2.60
SEPTEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 4.10 0.00 0.70	31 0.00 0.00 0.00	30 37.13 0.00 4.30	30 61.92 0.11 6.20

E = Estimated daily flow values recorded during this month; NR = Not Recorded
\+ = Flow data not recorded

TABLE 4.2-1 (Page 4 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

HAVANA INTERCEPTOR		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 29.80 0.00 4.20	31 88.60 0.70 4.50	31 43.42 0.24 6.00	31 20.15 0.22 0.43
NOVEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 136.30 0.00 14.40	30 53.80 0.10 3.60	30 54.51 0.15 6.80	22 11.50 0.17 0.76
DECEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
JANUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
FEBRUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	1 0.46 0.23 1.50
MARCH	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	28 21.24 0.21 1.50
APRIL	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 358.70 0.00 62.80	30 77.40 0.00 10.40	26 22.82 0.02 2.70	9 23.40 0.63 5.40
MAY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 95.10 0.00 10.30	31 276.60 1.00 20.90	31 351.79 0.41 78.00	19 53.82 0.26 12.00
JUNE	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 77.50 0.70 6.30	30 293.90 1.30 31.70	30 119.72 0.47 14.00	30 146.44 0.26 36.00
JULY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 113.70 0.80 7.20	31 119.10 1.00 4.90	31 87.13 0.36 12.00	28 182.97 0.46 71.00
AUGUST	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 118.60 0.70 11.20	31 113.00 0.00 12.20	31 94.61 0.43 10.00	31 53.45 0.37 4.10
SEPTEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 70.50 0.70 3.00	30 102.40 0.70 8.90	30 58.06 0.38 5.50	30 81.52 0.32 7.00

E = Estimated daily flow values recorded during this month; NR = Not Recorded

TABLE 4.2-1 (Page 5 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

NORTH UVALDA		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		31			31	31	31	31
	Total (ac-ft)		6.91			25.90	25.80	46.08	7.76
	Min (cfs)		T			0.30	0.20	0.11	0.11
	Max (cfs)		2.39			1.10	1.20	9.50	0.14
NOVEMBER	Days of Record		19			30	30	30	30
	Total (ac-ft)		0.47			54.20	16.70	20.31	6.88
	Min (cfs)		T			0.40	0.20	0.08	0.11
	Max (cfs)		0.20			3.60	1.40	1.20	0.12
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
APRIL	Days of Record	2*	30			30	30	27	NR
	Total (ac-ft)	0.00*	15.09			51.70	10.50	9.97	
	Min (cfs)	0.00*	T			0.30	0.10	0.13	
	Max (cfs)	0.00*	1.54			2.80	1.40	0.86	
MAY	Days of Record	31*	29			31	31	31	26
	Total (ac-ft)	16.15*	9.87			34.00	39.60	93.28	139.28
	Min (cfs)	0.00*	T			0.30	0.10	0.11	0.00
	Max (cfs)	2.37*	1.98			3.60	3.90	8.50	65.00
JUNE	Days of Record	30*	29			30	30	29	30
	Total (ac-ft)	30.87*	24.06			18.70	306.00	6.53	258.09
	Min (cfs)	0.00*	T			0.20	0.20	0.04	0.00
	Max (cfs)	2.38*	9.90			2.20	26.00	1.40	80.00
JULY	Days of Record	31*	29			31	31	21	31
	Total (ac-ft)	13.13*	32.76			171.40	126.60	113.81	0.00
	Min (cfs)	0.00*	0.18			0.20	0.10	0.06	0.00
	Max (cfs)	0.74*	8.57			15.00	12.40	13.00	0.00
AUGUST	Days of Record	27	3			31	31	31	31
	Total (ac-ft)	19.78	1.13			27.10	75.20	138.66	1.80
	Min (cfs)	0.00	0.18			0.20	0.00	0.08	0.00
	Max (cfs)	9.23	0.19			4.30	16.70	15.00	0.00
SEPTEMBER	Days of Record	30				30	30	30	30
	Total (ac-ft)	8.70				202.40	16.30	6.57	2.96
	Min (cfs)	0.00				0.20	0.00	0.09	0.00
	Max (cfs)	0.57				14.70	3.00	0.14	0.06

* North Uvalda Gage at old location; E = Estimated daily flow values recorded during this month; NR = Not Recorded; T = Trace Flow

TABLE 4.2-1 (Page 6 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH UVALDA		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		31			31	31	30	31
	Total (ac-ft)		15.21			37.40	49.00	48.06	26.52
	Min (cfs)		T			0.40	0.40	0.35	0.35
	Max (cfs)		3.97			2.80	3.50	6.00	0.54
NOVEMBER	Days of Record		18			30	30	28	30
	Total (ac-ft)		2.68			34.20	27.10	28.05	22.56
	Min (cfs)		T			0.40	0.30	0.25	0.30
	Max (cfs)		1.22			1.50	1.60	1.20	1.20
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	11
	Total (ac-ft)								6.66
	Min (cfs)								0.27
	Max (cfs)								0.33
APRIL	Days of Record		30			30	30	22	30
	Total (ac-ft)		8.47			147.20	33.90	22.12	28.96
	Min (cfs)		T			0.40	0.30	0.25	0.22
	Max (cfs)		1.18			25.80	2.50	1.40	0.33
MAY	Days of Record	17	29			31	31	31	31
	Total (ac-ft)	8.00	29.90			56.80	94.80	143.31	98.96
	Min (cfs)	0.00	T			0.60	0.40	0.42	0.23
	Max (cfs)	1.00	4.32			5.30	11.10	25.00	10.00
JUNE	Days of Record	30	29			30	30	23	30
	Total (ac-ft)	21.67	7.32			58.30	89.80	73.21	82.45
	Min (cfs)	0.00	T			0.60	0.20	0.54	0.59
	Max (cfs)	3.24	1.61			6.00	9.40	16.00	9.60
JULY	Days of Record	31	31			31	31	31	31
	Total (ac-ft)	1.91	5.15			73.30	48.90	55.54	102.35
	Min (cfs)	0.00	T			0.50	0.40	0.33	0.66
	Max (cfs)	0.62	0.98			8.30	4.50	4.80	20.00
AUGUST	Days of Record	31	29			31	31	31	31
	Total (ac-ft)	22.33	1.81			75.40	134.50	51.69	64.30
	Min (cfs)	T	T			0.50	0.60	0.33	0.45
	Max (cfs)	8.42	0.39			14.90	38.30	6.40	9.40
SEPTEMBER	Days of Record	30	28			30	30	30	30
	Total (ac-ft)	9.34	0.56			34.80	61.80	39.97	62.42
	Min (cfs)	T	T			0.40	0.30	0.38	0.41
	Max (cfs)	1.45	0.20			0.80	5.70	4.00	5.50

NR = Not Recorded; E = Estimated daily flow values recorded during this month; T = Trace Flow.

TABLE 4.2-1 (Page 7 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH PLANTS DITCH		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		12			31	31	31	31
	Total (ac-ft)		12.67			0.00	0.00	0.00	0.00
	Min (cfs)		0.46			0.00	0.00	0.00	0.00
	Max (cfs)		0.96			0.00	0.00	0.00	0.00
NOVEMBER	Days of Record		19			30	30	30	30
	Total (ac-ft)		17.44			0.00	0.00	0.00	0.00
	Min (cfs)		0.46			0.00	0.00	0.00	0.00
	Max (cfs)		0.49			0.00	0.00	0.00	0.00
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
APRIL	Days of Record	2	29			30	30	30	30
	Total (ac-ft)	0.30	26.74			0.00	0.00	0.00	0.00
	Min (cfs)	0.00	0.46			0.00	0.00	0.00	0.00
	Max (cfs)	0.15	0.53			0.00	0.00	0.00	0.00
MAY	Days of Record	31	29			31	31	31	31
	Total (ac-ft)	27.67	35.14			0.00	0.00	11.62	0.00
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	0.61	1.05			0.00	0.00	3.80	0.00
JUNE	Days of Record	30	29			30	30	30	30
	Total (ac-ft)	19.15	34.90			0.00	0.00	0.00	0.89
	Min (cfs)	0.00	0.15			0.00	0.00	0.00	0.00
	Max (cfs)	0.60	1.05			0.00	0.00	0.00	0.38
JULY	Days of Record	31	31			31	31	31	31
	Total (ac-ft)	4.73	0.91			0.00	0.00	0.00	0.00
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	0.60	0.21			0.00	0.00	0.00	0.00
AUGUST	Days of Record	31	29			31	31	31	31
	Total (ac-ft)	17.96	37.87			0.00	0.00	0.00	0.00
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	0.52	1.37			0.00	0.00	0.00	0.00
SEPTEMBER	Days of Record	20	28			30	30	30	30
	Total (ac-ft)	9.51	35.74			0.00	0.00	0.00	0.00
	Min (cfs)	T	T			0.00	0.00	0.00	0.00
	Max (cfs)	0.56	1.24			0.00	0.00	0.00	0.00

NR = Not Recorded; E = Estimated daily flow values recorded during this month; T = Trace Flow.

TABLE 4.2-1 (Page 8 of 11)

FLOW CHARACTERISTIC AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

LADORA WEIR		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89
OCTOBER	Days of Record		31			31	31	31	31
	Total (ac-ft)		38.94			10.40	5.10	0.00	13.86
	Min (cfs)		T			0.00	0.00	0.00	0.11
	Max (cfs)		3.30			2.70	2.60	0.00	2.10
NOVEMBER	Days of Record		19			30	30	30	30
	Total (ac-ft)		16.05			1.54	0.00	0.04	3.09
	Min (cfs)		T			0.00	0.00	0.00	0.00
	Max (cfs)		3.12			0.80	0.00	0.01	0.11
DECEMBER	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	NR	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
APRIL	Days of Record		30			30	30	30	NR
	Total (ac-ft)		23.63			0.00	0.00	0.01	
	Min (cfs)		T			0.00	0.00	0.00	
	Max (cfs)		6.97			0.00	0.00	0.00	
MAY	Days of Record		29			31	31	31	9
	Total (ac-ft)		0.00			0.00	0.00	35.88	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		T			0.00	0.00	3.40	0.00
JUNE	Days of Record		29			30	30	30	30
	Total (ac-ft)		0.00			0.00	53.00	49.13	0.00
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		T			0.00	13.60	1.20	0.00
JULY	Days of Record		31			31	31	31	31
	Total (ac-ft)		20.92			19.80	82.10	17.30	65.14
	Min (cfs)		0.00			0.00	0.00	0.00	0.00
	Max (cfs)		5.79			5.10	14.50	1.10	13.00
AUGUST	Days of Record	27	28			31	31	31	31
	Total (ac-ft)	71.09	0.00			20.40	0.00	89.65	4.09
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.02
	Max (cfs)	2.99	T			5.00	0.00	8.60	0.11
SEPTEMBER	Days of Record	30	28			30	30	30	30
	Total (ac-ft)	70.64	46.00			23.90	1.10	53.97	2.30
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	3.37	10.11			6.90	0.10	6.20	0.06

NR = Not Recorded; E = Estimated daily flow values recorded during this month; T = Trace Flow.

TABLE 4.2-1 (Page 9 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

SOUTH FIRST CREEK		WY82	WY83	WY84	WY85	WY86	WY87	WY88	WY89+
OCTOBER	Days of Record		31			31	31	31	NR
	Total (ac-ft)		0.00			68.10	29.20	52.70	
	Min (cfs)		0.00			0.70	0.20	0.51	
	Max (cfs)		T			1.60	1.00	1.90	
NOVEMBER	Days of Record		19			30	30	30	NR
	Total (ac-ft)		0.00			92.70	53.70	107.50	
	Min (cfs)		0.00			0.90	0.70	1.20	
	Max (cfs)		T			3.40	1.40	4.10	
DECEMBER	Days of Record		E			E	E	E	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
JANUARY	Days of Record		E			E	E	E	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
FEBRUARY	Days of Record		E			E	E	E	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
MARCH	Days of Record		E			E	E	E	NR
	Total (ac-ft)								
	Min (cfs)								
	Max (cfs)								
APRIL	Days of Record	2	30			30	30	27	25
	Total (ac-ft)	0.00	176.61			301.40	68.00	104.93	42.73
	Min (cfs)	0.00	T			0.70	0.70	1.60	0.65
	Max (cfs)	0.00	12.07			41.00	1.80	2.40	1.50
MAY	Days of Record	31	22			31	31	31	31
	Total (ac-ft)	1.71	430.91			95.00	222.40	179.70	95.23
	Min (cfs)	0.00	3.84			1.10	0.80	1.20	0.81
	Max (cfs)	0.76	94.49			3.90	36.30	13.00	5.60
JUNE	Days of Record	30	29			30	30	30	30
	Total (ac-ft)	4.37	122.78			49.20	239.30	92.09	81.52
	Min (cfs)	0.00	T			0.00	0.30	0.93	0.56
	Max (cfs)	1.84	7.46			2.60	71.80	3.10	0.31
JULY	Days of Record	31	26			31	31	31	31
	Total (ac-ft)	0.45	81.92			3.90	21.40	61.35	12.87
	Min (cfs)	0.00	T			0.00	0.00	0.24	0.00
	Max (cfs)	0.23	31.77			0.40	2.70	5.20	2.10
AUGUST	Days of Record	31	23			31	31	31	31
	Total (ac-ft)	5.34	214.17			6.70	6.30	37.55	24.40
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	2.34	61.80			1.40	1.10	3.00	3.40
SEPTEMBER	Days of Record	30	29			30	30	30	30
	Total (ac-ft)	119.07	0.00			7.60	4.40	25.67	6.27
	Min (cfs)	0.00	T			0.00	0.00	0.00	0.00
	Max (cfs)	50.79	T			0.90	0.20	1.40	0.56

NR = Not Recorded; E = Estimated daily values recorded during this month; T = Trace Flow; + = Data for New South First Creek Gaging Station.

TABLE 4.2-1 (Page 10 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

FIRST CREEK - OFFPOST		WY82	WY83	WY84	WY85	WY86[3]	WY87[3]	WY88	WY89[4]
OCTOBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						31 0.02 0.00 0.00	31 1.09 0.00 0.12	NR
NOVEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						30 1.09 0.01 0.03	30 1.51 0.01 0.04	NR
DECEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						E	NR	NR
JANUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						E	NR	NR
FEBRUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						E	NR	NR
MARCH	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						E	NR	NR
APRIL	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						30 52.94 0.56 1.13	NR	NR
MAY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						31 159.21 0.42 11.57	NR	NR
JUNE	Days of Record Total (ac-ft) Min (cfs) Max (cfs)						30 109.97 0.07 11.67	NR	NR
JULY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 0.76 0.00 0.02	31 5.16 0.00 0.82	NR	26 0.30 0.00 0.03
AUGUST	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 0.00 0.00 0.00	NR	NR	31 0.00 0.00 0.00
SEPTEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 0.00 0.00 0.00	NR	NR	30 0.00 0.00 0.00

NR = Not Recorded; E= Estimated daily flow values recorded during this month; T = Trace Flow.
3 = Source: Ebasco, 1989a; 4 = New gaging station began operation in July 1989.

TABLE 4.2-1 (Page 11 of 11)

FLOW CHARACTERISTICS AT RMA GAGING STATIONS

Total = Total Monthly Flow; Min = Minimum Daily Mean Flow; Max = Maximum Daily Mean Flow

NORTH FIRST CREEK		WY82	WY83	WY84	WY85	WY86[3]	WY87[3]	WY88	WY89[4]
OCTOBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 65.00 0.50 2.40	31 0.00 0.00 0.00	NR	NR
NOVEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 193.80 1.50 6.40	30 0.00 0.00 0.00	NR	NR
DECEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
JANUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
FEBRUARY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
MARCH	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					E	E	NR	NR
APRIL	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 262.90 0.50 15.90	30 63.70 0.50 1.60	NR	25 34.62 0.47 1.20
MAY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 69.50 0.10 4.50	31 235.90 0.10 31.20	NR	31 76.11 0.40 3.60
JUNE	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 5.40 0.00 0.50	30 257.50 0.00 80.90	NR	30 70.59 0.00 4.00
JULY	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 0.00 0.00 0.00	31 0.10 0.10 0.00	NR	31 0.00 0.00 0.00
AUGUST	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					31 0.00 0.00 0.00	NR	31 0.32 0.00 0.09	1 0.00 0.00 0.00
SEPTEMBER	Days of Record Total (ac-ft) Min (cfs) Max (cfs)					30 0.00 0.00 0.00	NR	30 0.21 0.00 0.01	NR

NR = Not Recorded; E= Estimated daily values recorded during this month; T = Trace Flow.
3 = Source: Ebasco 1989a; 4 = New gaging station began operation in July 1989.

This period was selected because it corresponds to the greatest rainfall at RMA, and thus serves as a good indicator of watershed response to rainfall. Unit runoff values have been calculated for September, which is generally a dryer period, to evaluate baseflow conditions at these stations.

The Havana Interceptor conveyed the largest volume of water to RMA in WY89 with 460 ac-ft recorded during April through August. This volume represents a unit runoff from the 5.22 mi^2 drainage area of 1.65 in., about 21 percent of the precipitation measured at Stapleton Airport during the same period (Table 4.2-2). A downward trend in the 1986-1989 runoff is expressed in percentages of the measured Stapleton precipitation (38.20, 26.67, 23.78, 21.32) but the significance is unknown. More than likely it is related to variations in rainfall patterns not adequately reflected by a single gage. The volume of inflow to RMA via the Havana Interceptor was about 44 percent of the total Irondale Gulch drainage basin inflow in WY89, although the drainage area is only about 38 percent of the total RMA drainage.

The second largest natural inflow to RMA during WY89 was measured at the South Uvalda monitoring station. During April through August an inflow to RMA of 377.02 ac-ft was measured. The unit runoff from its 7.7 mi^2 drainage area was 0.92 in., about one half that of the Havana Interceptor. The unit runoff for these 5 months over the 4 years of records has been quite consistent (1.00, 0.98, 0.84 and 0.92 in). Although the drainage area contributing to the South Uvalda is more than 57 percent of the Irondale Gulch drainage basin above RMA, the volume of runoff produced was only 35 percent of the total in WY89.

The stream flow gages measuring the smallest (Peoria Interceptor - 0.644 mi^2) and the largest (First Creek - 26.38 mi^2) drainage areas measured about the same volume of flow during April through August 1989. The volume measured at the Peoria Interceptor gage was 213.11 ac-ft compared to 256.75 ac-ft at South First Creek.

The unit runoff of the Peoria Interceptor drainage area for April through August in WY89 was 6.20 in., 80.06 percent of the Stapleton precipitation. This unit runoff, though comparable to the 6.39 in. of 1988, is considerably higher than the 2.20 and 3.49 in. for 1986 and 1987, respectively. Likewise, the runoff as a percentage of the Stapleton precipitation was considerably higher in 1988 and 1989 (62.61 and 80.06 percent) compared to 1986 and 1987 (30.62 and 29.46 percent). Although rainfall patterns could be a

Table 4.2-2 UNIT RUNOFF VALUES FOR THE MAJOR DRAINAGE PATHWAYS ON RMA (Page 1 of 4)				
SOUTH UVALDA				
DRAINAGE AREA = 7.723 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	411.00	401.90	345.87	377.02
Unit Runoff (in)	1.00	0.98	0.84	0.92
Unit Runoff as % of Precipitation	13.90	8.23	8.22	11.81
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	34.80	61.80	39.97	62.42
Unit Runoff (in)	0.08	0.15	0.10	0.15
Unit Runoff as % of Precipitation	19.65	21.43	10.78	9.78
PEORIA INTERCEPTOR				
DRAINAGE AREA = .644 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	75.50	119.90	219.56	213.11
Unit Runoff (in)	2.20	3.49	6.39	6.20
Unit Runoff as % of Precipitation	30.62	29.46	62.61	80.06
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	4.10	0.00	37.13	61.92
Unit Runoff (in)	0.12	0.00	1.08	1.80
Unit Runoff as % of Precipitation	27.76	0.00	120.12	116.31

[1] Precipitation values are recorded at Stapleton International Airport.

[2] Days of record for each of the designated months may vary between water years (see Table 4.2-1). Some months may lack complete flow records.

Table 4.2-2 UNIT RUNOFF VALUES FOR THE MAJOR DRAINAGE PATHWAYS ON RMA (Page 2 of 4)				
HAVANA INTERCEPTOR				
DRAINAGE AREA = 5.22 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	763.60	880.00	676.07	460.08
Unit Runoff (in)	2.74	3.16	2.43	1.65
Unit Runoff as % of Precipitation	38.20	26.67	23.78	21.32
SEPTEMBER2				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	70.50	102.40	58.06	81.52
Unit Runoff (in)	0.25	0.37	0.21	0.29
Unit Runoff as % of Precipitation	58.89	52.55	23.17	18.89
SOUTH FIRST CREEK				
DRAINAGE AREA = 26.38 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89[3]
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	456.20	557.4	475.62	256.75
Unit Runoff (in)	0.32	0.40	0.34	0.18
Unit Runoff as % of Precipitation	4.52	3.34	3.31	2.35
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	7.60	4.40	25.67	6.27
Unit Runoff (in)	0.01	0.003	0.02	0.004
Unit Runoff as % of Precipitation	1.26	0.45	2.03	0.29

[1] Precipitation values are recorded at Stapleton International Airport.

[2] Days of record for each of the designated months may vary between water years (see Table 4.2-1). Some months may lack complete flow records.

[3] New Gaging Station Location

Table 4.2-2 UNIT RUNOFF VALUES FOR THE MAJOR DRAINAGE PATHWAYS ON RMA (Page 3 of 4)				
SOUTH PLANTS DITCH				
DRAINAGE AREA = 0.55 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	0.00	0.00	11.62	0.89
Unit Runoff (in)	0.00	0.00	0.40	0.03
Unit Runoff as % of Precipitation	0.00	0.00	3.88	0.39
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	0.00	0.00	0.00	0.00
Unit Runoff (in)	0.00	0.00	0.00	0.00
Unit Runoff as % of Precipitation	0.00	0.00	0.00	0.00
BASIN A				
DRAINAGE AREA = 0.055 SQUARE MILES				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	7.87	6.04	3.14	1.27
Unit Runoff (in)	2.68	2.06	1.07	0.43
Unit Runoff as % of Precipitation	37.37	17.38	10.48	5.59
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	0.19	2.30	0.02	0.06
Unit Runoff (in)	0.06	0.78	0.01	0.02
Unit Runoff as % of Precipitation	15.06	112.01	0.76	1.32

[1] Precipitation values are recorded at Stapleton International Airport.

[2] Days of record for each of the designated months may vary between water years (see Table 4.2-1). Some months may lack complete flow records.

Table 4.2-2 UNIT RUNOFF VALUES FOR THE MAJOR DRAINAGE PATHWAYS ON RMA (Page 4 of 4)				
HIGHLINE LATERAL				
DRAINAGE AREA = CONTROLLED FLOW FROM SOUTH PLATTE RIVER				
	WY 86	WY 87	WY 88	WY 89
APRIL - AUGUST[2]				
Precipitation (in)[1]	7.18	11.85	10.21	7.75
Total Flow Volume (ac-ft)	145.00	462.10	1252.45	460.99
Unit Runoff (in)	NA	NA	NA	NA
Unit Runoff as % of Precipitation	NA	NA	NA	NA
SEPTEMBER[2]				
Precipitation (in)[1]	0.43	0.70	0.90	1.55
Total Flow Volume (ac-ft)	162.70	0.00	338.18	0.00
Unit Runoff (in)	NA	NA	NA	NA
Unit Runoff as % of Precipitation	NA	NA	NA	NA

1 Precipitation values are recorded at Stapleton International Airport.

2 Days of record for each of the designated months may vary between water years (see Table 4.2-1). Some months may lack complete flow records.

partial cause of this large difference, major changes in the watershed also have taken place, such as more impermeable surfaces and more irrigation.

The 5-month runoff volume entering RMA via First Creek was 256.75 ac-ft, a unit runoff of only 0.18 in. This is substantially smaller than the 0.32 in., 0.40 in. and 0.34 in. unit runoffs of 1986, 1987 and 1988, respectively. The variability is most likely caused by differences in rainfall intensities and amounts that can occur over a watershed area of this size during the summer thunderstorm season. Runoff from an intense storm can vary substantially on an undeveloped portion of the watershed compared to a developed portion.

The measured outflow of First Creek at the North First Creek monitoring station, although including 10.32 additional mi^2 of drainage area and imported water, was significantly less than the inflow at South First Creek (181.32 ac-ft vs 232.35 ac-ft, April through July). This relationship is typical of previous years (Table 4.2-1) and represents a loss of surface flow to infiltration, evaporation and transpiration.

4.2.1.2 Variability of Flow Rates

The variability of flow rates affects the accuracy of measurement, the more variable being generally the most difficult to measure accurately. The ratio of the maximum daily discharge to the mean daily discharge is an index of variability. These indices calculated monthly for WY89 are shown in Table 4.2-3 for the 11 stream gaging stations.

Stations that carry runoff from rainfall events tend to have a higher variability index than those controlled by humans. However, the North Uvalda station during May and June, and the Highline Lateral during June are exceptions.

A second index, the ratio of the instantaneous maximum discharge to the mean daily discharge displays somewhat the same pattern, as shown in Table 4.2-4. The flows in the Havana Interceptor were the most variable, considerably more so than flows from the other two small off-site tributary drainages, Peoria Interceptor and South Uvalda. Maximum discharges at South First Creek were relatively small in comparison to the mean daily discharge.

Table 4.2-3 Ratio of Daily Maximum Discharge to Mean Daily Discharge

	Oct. '88	Apr. '89	May '89	June '89 (dimensionless)	July '89	Aug. '89	Sept. '89
Irondale Gulch Drainage Basin							
Havana Interceptor	1.3	4.2*	8.6*	14.4	23.7	4.7	5.0
Peoria Interceptor	2.4	7.0*	6.0	15.8	15.0	7.2	6.2
Ladora Weir	9.1	NR	--	--	11.8	1.6	1.5
South Uvalda	1.2	8.0*	6.2	8.0	11.8	9.4	5.5
North Uvalda	1.1	NR	28.3	18.6	--	2.7	1.2
Highline Lateral	6.6	--	3.5	20.6	--	15.6	--
South Plants Ditch	--	--	--	3.8	--	--	--
First Creek Drainage Basin							
South First Creek	NR	1.7*	3.7	2.2	10.0	8.5	5.1
North First Creek	NR	1.7*	3.0	3.3	--	--	--
First Creek Off-Post	NR	NR	NR	NR	3.0*	NR	NR
South Platte Drainage Basin							
Basin A	--	--	9.0	12.0	--	--	--

* Partial Month
NR No Record
-- Mean Daily Discharge = 0

Table 4.2-4 Ratio of Instantaneous Maximum Discharge to Mean Daily Discharge

	Oct. '88	Apr. '89	May '89 (dimensionless)	June '89	July '89	Aug. '89	Sept. '89
Irondale Gulch Drainage Basin							
Havana Interceptor	2.2	11.5*	57.9*	378.4	524.3	98.8	88.6
Peoria Interceptor	8.7	22.2*	41.0	37.5	87.9	75.0	28.0
Ladora Weir	23.0	NR	--	--	12.7	1.6	1.5
South Uvalda	2.2	53.1*	94.4	91.7	117.6	152.0	122.0
North Uvalda	1.1	NR	100.9	48.4	--	2.7	1.2
Highline Lateral	34.1	--	3.7	22.8	--	21.7	10.9
South Plants Ditch	--	--	--	180.0	--	--	--
First Creek Drainage Basin							
South First Creek	NR	2.2*	7.3	3.9	23.8	18.0	--
North First Creek	NR	2.1*	5.8	6.2	--	--	--
First Creek Off-Post	NR	NR	NR	NR	4.0	--	NR
South Platte Drainage Basin							
Basin A	--	--	45.0	52.0	--	--	--

* Partial Month
NR No Record
-- Mean Daily Discharge = 0

4.2.2 LAKE AND POND STAGE DATA

Average monthly stage values for Upper Derby Lake, Ladora Lake, Lake Mary, and Havana Pond for WY88 and WY89 are presented in Table 4.2-5. Stage/volume and stage/area relationships have been established by previous contractors (Ebasco, Inc., 1989a, Appendix A-2). Weekly stage readings were started by CMP in April 1988. Stage data reported in Table 4.2-5 for October 1985 to December 1987 were taken from the WRI report (Ebasco, et al, 1989a). Sections 4.2.2.1 - 4.2.2.5 compare historical stage data to that compiled in the surface-water CMP.

4.2.2.1 Upper Derby Lake

Upper Derby Lake was essentially dry from mid-1986 until May 1988. It reached maximum storage in July 1988, then stayed at stages of 5 ft to over 6 ft through the first 2 months of WY89.

As in the past water year, storage was drawn to zero by March 1989, then increased again to a maximum in June. The maximum stage was 7.70 ft (5,255.47 ft-msl), measured June 6, 1989, representing about 48.96 ac-ft of storage volume.

4.2.2.2 Lower Derby Lake

Historically, the stage of Lower Derby Lake has fluctuated between about 14 and 17 ft without a definable seasonal pattern. The stages in WY89, however, stayed between 16.9 ft (5,247.07 ft-msl) and 15.1 ft (5,245.27 ft-msl) until July. In late July the stage started decreasing and increased on September 26 to 278.44 ac-ft, 282.90 ac-ft less than the maximum stage measured at the beginning of the water year (16.90 ft).

4.2.2.3 Ladora Lake

Consistent with the historical record, the Ladora Lake stage varied by only about 1 ft during WY89. The stages varied between a high of 12.40 ft on February 22 (5,219.51 ft-msl) to a low of 11.30 ft on September 12 and 26 (5,218.41 ft-msl). The stage of Ladora Lake is maintained at a relatively constant level to meet the process water needs at RMA.

Table 4.2-5 Evaporation, Precipitation, and Lake Stage Data (Page 1 of 2)

		Climatic		Lake and Pond Stages[3]				
Month	Water Year	Total Precip.[1] (inches)	Total Evap.[2] (inches)	Upper Derby (feet)	Lower Derby (feet)	Ladora Lake (feet)	Lake Mary (feet)	Havana Pond (feet)
10/85	WY86	0.77	2.73	2.2	16.9	11.8	1.12	3.10
11/85		1.20	1.89	1.8	16.4	12.3	0.95	2.01
12/85		0.66	0.63	1.4	16.3	12.5	1.38	0.35
01/86		0.22	0.49	1.4	16.0	12.4	1.54	0
02/86		0.65	0.63	1.1	15.8	12.5	1.61	0
03/86		0.43	1.12	0.6	15.7	12.5	1.59	0
04/86		2.59	2.24	0	15.3	12.4	1.48	0
05/86		1.30	3.50	0.8	16.2	12.4	1.56	0.70
06/86		1.07	5.75	0	16.0	12.3	1.39	1.38
07/86		1.69	6.15	0	15.4	11.9	1.02	1.43
08/86		0.53	5.45	0	16.4	11.6	0.67	2.07
09/86		0.43	4.46	0	15.1	11.5	0.35	1.75
WY Total		11.54	35.04					
10/86	WY87	1.29	2.73	0	15.8	11.85	0.09	1.39
11/86		1.05	1.89	0	15.4	11.9	0.21	3.01
12/86		0.31	0.63	0	15.0	12.2	0.45	1.07
01/87		0.68	0.49	0	14.7	12.3	0.45	0.40
02/87		1.21	0.63	0	14.4	12.3	0.60	0.82
03/87		1.34	1.12	0	14.3	12.4	0.83	1.33
04/87		1.03	2.24	0	14.2	12.4	0.96	1.44
05/87		4.64	3.50	0	14.2	12.3	0.91	1.60
06/87		3.42	6.68	0	14.4	12.3	0.80	3.31
07/87		0.76	6.78	1.3	16.9	12.4	1.00	4.33
08/87		2.00	5.63	0	16.1	12.0	1.25	2.57
09/87		0.70	6.20	0	15.9	11.7	0.96	2.87
WY Total		18.43	38.52					

1 Precipitation values are recorded from Stapleton International Airport.
2 Evaporation values are based on pan evaporation data from Cherry Creek Reservoir. Pan coefficient is 0.7 inches.
3 Lake and pond stage data represent average monthly values.
NR Not recorded.

Note: A 0 stage value for Upper Derby Lake or Havana Pond indicates that the water level was below the staff gage or the lake or pond was dry.

Table 4.2-5 Evaporation, Precipitation, and Lake Stage Data (Page 2 of 2)

Month	Water Year	Climatic Total Precip.[1] (inches)	Climatic Total Evap.[2] (inches)	Upper Derby (feet)	Lake and Pond Stages[3] Lower Derby (feet)	Ladora Lake (feet)	Lake Mary (feet)	Havana Pond (feet)
10/87	WY88	1.24	3.60	0	15.3	11.6	0.67	1.89
11/87		1.62	1.89	0	14.7	11.7	0.52	2.72
12/87		1.30	0.63	0	14.6	12.0	0.62	2.15
01/88		0.40	0.49	NR	NR	NR	NR	NR
02/88		0.60	0.63	NR	NR	NR	NR	NR
03/88		1.28	1.12	NR	NR	NR	NR	NR
04/88		0.65	2.24	0	13.79	12.20	1.33	1.23
05/88		4.26	3.50	2.83	14.28	12.17	1.18	3.29
06/88		1.28	5.75	6.98	14.13	12.42	0.97	2.88
07/88		2.19	5.48	4.77	16.48	12.15	1.07	2.46
08/88		1.83	5.81	5.30	16.72	11.96	0.65	2.75
09/88		0.90	4.62	5.18	16.88	11.74	0.28	2.39
WY Total		17.55	35.76					
10/88	WY89	0.06	4.80	6.65	16.88	12.05	0.16	1.82
11/88		0.47	2.70	5.22	16.45	12.16	0.30	0
12/88		1.04	0.90	NR	NR	NR	NR	NR
01/89		1.14	0.70	NR	NR	NR	NR	NR
02/89		0.66	0.90	NR	15.78	12.35	0.83	0
03/89		0.56	1.60	0	15.90	12.27	1.02	0
04/89		1.00	3.20	1.03	15.70	12.20	0.86	1.69
05/89		3.83	6.80	3.22	15.26	12.12	0.62	2.76
07/89		1.64	9.98	5.38	15.12	11.85	0.71	2.13
08/89		1.28	7.64	5.05	13.66	11.98	0.72	15.19
09/89		1.55	6.80	4.40	12.75	11.33	0.77	2.47
WY Total		15.27	52.96					

1 Precipitation values are recorded from Stapleton International Airport.
2 Evaporation values are based on pan evaporation data from Cherry Creek Reservoir. Pan coefficient is 0.7 inches.
3 Lake and pond stage data represent average monthly values.
NR Not recorded.

Note: A 0 stage value for Upper Derby Lake or Havana Pond indicates that the water level was below the staff gage or the lake or pond was dry.

4.2.2.4 Lake Mary

The measured stages of Lake Mary during WY89 were consistent with the historical record, varying between a low of 0.12 ft on October 25 (5,202.51 ft-msl) to a high of 1.08 ft on February 28 (5,203.47 ft-msl). No stage/volume relationship is available for Lake Mary.

4.2.2.5 Havana Pond

The measured stages in Havana Pond during WY89 were consistent with the historical record. The stage varied between below gage 0 (5,244.08 ft-msl) during February and March to a maximum of 4.81 ft (5,248.89 ft-msl) measured on May 16. The maximum stage represents a storage volume of 78.26 ac-ft. This maximum occurred after a 3-day rain, May 13-15, which totaled 2.02 in. at Stapleton Airport.

4.2.3 EVAPORATION AND PRECIPITATION DATA

Monthly evaporation and precipitation data for WY86, WY87, WY88 and WY89 are presented in Table 4.2-5. Evaporation measured during WY89 was substantially higher than the previous three years (52.96 in. vs. 25.04, 38.52, and 35.76 in.). The major increases were in October 1988, and July and August of 1989.

Precipitation during WY89 was near the 30-year normal. However, the precipitation during the first 7 months was below normal, reaching a total deficiency of 4.87 in. by the end of April. Above normal precipitation during the last 5 months of the water year resulted in a total slightly above normal.

4.2.4 SEWAGE TREATMENT PLANT TRENDS AND EXTREMES

Discharge from the Sewage Treatment Plant (STP) is treated water that is used on RMA. The water is discharged into a plastic-lined channel that leads to First Creek. The amount of water discharged from the plant is recorded daily by Army personnel and compiled weekly by Stollar personnel. Discharge records for WY88 are provided in Appendix A-10 (RLSA, 1990a) and for WY89 in A-2 (RLSA, 1990b).

A total of 5,271,400 gallons of water was discharged from the STP during WY89 (Table 4.2-6). The monthly discharge varied from a minimum of 118,400 gal during April 1989 to a maximum of 862,400

gal during August 1989. The average monthly discharge for WY89 was 439,283 gal or 14,384 gal/day. The minimum weekly discharge was 13,100 gal during the week of April 25, 1989, and the maximum weekly discharge of 218,900 gal was during the week of August 18, 1989 (Figure 4.1-43 and Appendix A-10, RLSA, 1990b).

A comparison of Sewage Treatment Plant Discharge records from WY86, WY87 (Table 4.1-14), WY88, and WY89 (Table 4.2-6) shows a substantial increase in discharge after WY87. Yearly discharge increased about 1.5 million gal per year after WY87.

4.3 PRE-CMP SURFACE-WATER QUALITY DATA ASSESSMENT

This section reviews and assesses previously reported (pre-CMP) surface-water quality data. Historical sampling locations are documented and analytical results are tabulated. The results of previous studies of RMA surface-water quality are summarized.

4.3.1 HISTORICAL DETECTIONS AT CURRENT CMP SURFACE-WATER SITES

Historical surface-water sampling records have been compiled for 1979 through 1987. The methods used to gather and evaluate this historical data are discussed in the following sections.

4.3.1.1 Historical Database for Surface-Water Quality at RMA

The largest single source of surface-water quality information at RMA is managed by the RMA Program Manager's data management contractor, DPA, in Denver, Colorado. In an ongoing effort to assimilate and validate environmental data, DPA has obtained digital data files from the overall USATHAMA data management contractor, Potomac Research, Inc., and from other current and previous RMA contractors. Surface-water quality is one of several data types being incorporated into this file.

The digital data files are accessed through a User Data Management System (UDMS) that is currently managed by DPA. The Stollar team obtained and processed a November 17, 1989, data acquisition file of the surface-water quality records by modem transfer. This data record file was updated on October 17, 1990, with additional analytical data which had been uploaded in the UDMS since November 17, 1989. These records will be used for subsequent comparison with results from the FY88

Table 4.2-6 Sewage Treatment Plant Monthly Flow Summaries, Water Years 1988 and 1989

Month	Monthly Total (gallons)	Daily Average (gpd)	Daily Average (gpm)
WY88			
October	266,500	8,597	5.97
November	231,000	7,700	5.35
December	335,500	10,823	7.52
January	374,200	12,071	8.38
February	528,200	18,214	12.65
March	573,400	18,497	12.85
April	571,000	19,033	13.22
May	643,000	20,742	14.40
June	556,200	18,540	12.88
July	510,500	17,017	11.82
August	696,500	22,468	15.60
September	633,100	21,103	14.65
Average	493,258	16,234	11.27
TOTAL FOR YEAR	5,919,100		
WY89			
October	438,600	14,148	9.83
November	452,000	15,067	10.46
December	400,900	12,932	8.98
January	446,800	14,413	10.01
February	264,800	9,457	6.57
March	340,000	10,968	7.62
April	118,400	3,947	2.74
May	334,000	10,774	7.48
June	377,900	12,597	8.75
July	652,100	21,035	14.61
August	862,400	27,819	19.32
September	583,500	19,450	13.51,
Average	439,283	14,384	9.99
TOTAL FOR YEAR	5,271,400		

gpd = gallons per day
gpm = gallons per minute

and FY89 CMP presented in Section 4.4 of this report. More than 20,000 water-quality records representing data collected between 1979 and 1987 were analyzed. Data sources included the 360 Degree Monitoring Program (1979-1986) and Tasks 4, 39, and 44 (1985-1987).

4.3.1.1.1 Intended Use of the Surface-Water Quality Historical Database

Results of the database analyses will be used for gross comparison of water-quality trends with current data. For example, the results may be useful in determining whether an analyte reported in current data are consistent with historical data.

4.3.1.1.2 Analytical Procedures Used to Construct the Surface-Water Quality Historical Database

The first analytical procedure was extraction from the database of site data corresponding to CMP surface-water sampling sites. Site correlation is summarized in Table 3.3-1. CMP data in the database were not used. For example, referring to Table 3.3-1, for site SW01001, data from historical sites 1DDCD and 1-001 were extracted from the database to form a historical file for that site. For some CMP sites, historical correlation was not established; therefore, no historical file was created. In several cases, correlated historical and CMP sampling sites do not exactly correspond to the same sampling location. Where maps indicated that sampling sites represented measurements from locations exposed to similar environmental conditions, a correlation was drawn. All sampling locations used to construct Table 3.1-1 are shown on Figure 3.3-1. Sampling sites associated with the 360 Degree Monitoring Program were derived from historical hand-plotted location maps. Survey coordinates were used to locate most of the CMP and (ESE 1989a) sampling sites. All locations shown on Figure 3.3-1 represent approximate positions of sampling locations.

The second analytical procedure was statistical processing of historical files. Files were evaluated for number of samples, number of detections, and minimum, maximum, and average detection values. Processing these files revealed a few anomalies in the data. The number of samples reported may include duplicate data resulting from either a duplicate or diluted analysis. Information on the historical files is not sufficient to differentiate or eliminate records from the statistical treatment. Some of the historical files were coded with an "N" in a field for validity. The field is no longer used, and the representation of the qualifier is unknown (James Clark, DPA, personal communication, 1989); therefore, the historical files may contain ambiguous data. The results of the statistical treatment of the historical files are

presented in Table 4.3-1 and Table 4.3-2. The minimum values indicate the lowest detected value for a given analyte. Table 4.3-1 and Table 4.3-2 allow for comparison of the range of occurrence of a given organic or inorganic analyte, respectively, at a given site with CMP data. The type of analysis for a given analyte was not differentiated; therefore, statistics for occurrence of analytes may be based on several analytical methods. Minimum, maximum and average concentrations of analytes were based only on values above the detection limit(s) at a given site.

4.3.1.1.3 Evaluation of Historical Surface-Water Analytical Data

Table 4.3-1 and Table 4.3-2, which were compiled from the comprehensive database, provide an indication of historical organic compound and trace inorganic constituent detections reported in the database. Trace inorganic constituents are defined as those generally occurring at concentrations less than 0.1 mg/L in natural waters. A total of 328 organic compound detections and 47 (includes arsenic total) selected metal inorganic detections in surface water are reported historically for sites corresponding to CMP surface-water sampling sites. FY88 and FY89 CMP data and data from historical sites not corresponding to CMP sites were not included in the analysis.

As shown in Table 4.3-1, organic compounds were detected historically at current CMP surface-water sampling sites. Compounds detected historically at three or more current CMP sites are listed chronologically as follows, according to the number of sites at which a compound was detected:

Compound	No. of Sites
DBCP	11
Chloroform (CHCL3)	8
Dieldrin (DLDRN)	4
Aldrin (ALDRN)	6
DIMP	8
Chlorophenyl methylsulfone (CPMSO2)	5
Dicyclopentadiene (DCPD)	6
Benzothiazole (BTZ)	3
Chlorophenyl methylsulfoxide (CPMSO)	3
Chlorophenyl methylsulfide (CPMS)	3
Endrin (ENDRN)	3

Table 4.3-1 Historical Detections of Organic Compounds at CMP Surface-Water Sampling Sites (Page 1 of 3)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW01001	DBCP	19	1	4.4100	4.4100	4.4100
SW01002	ALDRN	5	1	0.5300	0.5300	0.5300
	BTZ	1	1	18.4000	18.4000	18.4000
	C6H6	4	1	1.9800	1.9800	1.9800
	CHCL3	5	1	87.0000	87.0000	87.0000
	CL6CP	4	1	0.3080	0.3080	0.3080
	CPMS	5	2	2.1900	53.0000	27.5950
	CPMSO	5	3	7.2200	200.0000	87.7733
	CPMS02	5	4	85.8000	298.0000	198.4500
	DBCP	5	3	0.3360	25.3000	8.9053
	DCPD	5	1	20.7000	20.7000	20.7000
	DLDRN	5	4	0.1360	1.0200	0.6920
	ENDRN	5	1	0.7700	0.7700	0.7700
	ISODR	5	1	1.1900	1.1900	1.1900
	MEC6H5	4	2	1.5100	8.3700	4.9400
SW01003	ALDRN	13	3	0.0400	0.2400	0.1233
	CHCL3	9	7	14.0000	421.0000	85.9857
	CPMSO2	9	1	31.3000	31.3000	31.3000
	DBCP	30	30	0.2850	114.0000	6.9045
	DCPD	8	1	3.0000	3.0000	3.0000
	DLDRN	13	6	0.1300	2.5300	0.9300
	ENDRN	13	2	0.0300	0.0805	0.0553
SW02002	DBCP	21	4	0.3700	4.8500	1.5325
	DCPD	14	4	0.7000	712.0000	219.7000
	DIMP	21	3	24.6000	303.0000	143.5333
SW02003	CHCL3	7	6	1.0000	114.0000	27.0833
	PPDDE	5	1	0.0300	0.0300	0.0300
SW05001	CHCL3	5	1	6.0000	6.0000	6.0000
SW70002	DIMP	24	1	10.1000	10.1000	10.1000
SW08001	ALDRN	1	1	0.1620	0.1620	0.1620
	DBCP	28	3	0.2000	11.4000	3.9367
SW08002	DBCP	11	1	0.3100	0.3100	0.3100
	DIMP	11	1	127.0000	127.0000	127.0000
SW11001	111TCE	6	2	1.6600	2.9300	2.2950
	ALDRN	6	1	0.2450	0.2450	0.2450
	BTZ	3	3	3.6500	12.0000	9.2167
SW11003	BTZ	2	2	2.0600	2.0600	2.6000

Table 4.3-1 Historical Detections of Organic Compounds at CMP Surface-Water Sampling Sites
(Page 2 of 3)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW24001	ALDRN	4	4	0.2470	2.9800	1.0465
	CHCL3	5	2	4.8500	9.6600	7.2550
	DBCP	23	16	0.1500	387.0000	35.9725
	DIMP	7	1	2.8600	2.8600	2.8600
	DLDRN	4	4	0.0989	0.9360	0.3317
SW24002	DBCP	33	1	1.5000	1.5000	1.5000
	DIMP	26	2	12.1000	59.3000	35.7000
SW24003	CHCL3	3	1	1.0000	1.0000	1.0000
	CPMS	4	1	7.0000	7.0000	7.0000
	CPMSO	4	1	72.0000	72.0000	72.0000
	CPMSO2	4	1	35.0000	35.0000	35.0000
	DBCP	41	21	0.1600	15.1000	4.0129
	DCPD	16	2	0.2000	2030.0000	1015.1000
	DIMP	24	14	4.1200	321000.0000	23080.9014
SW31002	CHCL3	5	2	2.0000	3.5400	2.7700
SW36001	111TCE	5	3	2.3000	3.2500	2.7567
	112TCE	5	4	2.1200	5.9300	3.9800
	11DCE	5	4	1.7800	5.7500	4.3800
	12DCE	5	4	3.4100	11.3000	8.4800
	ALDRN	6	3	0.9830	13.7000	5.9177
	C6H6	5	5	1.7200	180.0000	54.6240
	CH2CL2	5	1	7.8500	7.8500	7.8500
	CHCL3	6	5	190.0000	567.0000	414.4000
	CL6CP	4	2	1.2500	2.4500	1.8500
	CLC6H5	5	5	15.8000	1750.0000	1087.1600
	CPMS	5	5	4.4700	44.3000	23.5500
	CPMSO	5	5	25.8000	87.1000	55.0800
	CPMSO2	5	5	106.0000	1540.0000	944.6000
	DBCP	18	17	2.2000	179.0000	80.2729
	DCPD	6	4	11.6000	70.2000	32.7500
	DIMP	19	1	32.3000	32.3000	32.3000
	DLDRN	6	5	3.7500	20.0000	9.4800
	DMMP	5	1	17.3000	17.3000	17.3000
	ENDRN	6	4	1.3900	7.2200	3.8400
	ETC6H5	5	4	6.4600	102.0000	51.5900
	ISODR	6	1	1.4500	1.4500	1.4500
	MEC6H5	5	4	1.8900	41.2000	20.8600
	MIBK	3	3	104.0000	2800.0000	1051.3333
	OXAT	5	1	27.0000	27.0000	27.0000
	PPDDT	6	1	54.7000	54.7000	54.7000
	TCLEE	6	6	43.1000	127.0000	89.0667
	TRCLE	5	5	19.7000	62.2000	44.6800
	XYLEN	5	5	17.5000	285.0000	152.0800

Table 4.3-1 Historical Detections of Organic Compounds at CMP Surface-Water Sampling Sites
(Page 3 of 3)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW37001	12DCLE	6	1	0.7540	0.7540	0.7540
	CPMS02	8	1	5.2000	5.2000	5.2000
	DBCP	21	1	0.5500	0.5500	0.5500
	DCPD	12	5	14.2000	178.0000	77.9800
	DIMP	21	21	10.0000	1790.0000	474.9810
	DITH	8	2	2.2100	2.7600	2.4850

µg/l = micrograms per liter

Table 4.3-2 Historical Detections of Trace Inorganics at CMP Surface-Water Sampling Sites

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (μg/l) Minimum	Maximum	Average
SW01001	As	2	1	2.5600	2.5600	2.5600
SW01002	As	1	1	11.5000	11.5000	11.5000
	As[1]	1	1	290000.0000	290000.0000	290000.0000
	Zn	1	1	40.0000	40.0000	40.0000
SW01003	As[1]	6	4	10.20000	344000.0000	86372.5500
SW02002	As[1]	1	1	21.8000	21.8000	21.8000
SW02003	As	5	4	18.8000	381000.0000	95747.2000
SW02004	Zn	1	1	78.8000	78.800	78.8000
SW05001	As	2	1	3.7800	3.7800	3.7800
SW07002	Cr	2	1	18.2000	18.2000	18.2000
	Pb	2	1	41.3000	41.3000	41.3000
SW08002	Zn	1	1	74.5000	74.5000	74.5000
SW11001	As	3	1	4.6000	4.6000	4.6000
	Zn	3	2	22.0000	83.1000	52.5500
SW11002	As	3	1	4.2000	4.2000	4.2000
	Cr	3	1	48.7000	48.7000	48.7000
	Cu	4	2	10.7000	12.7000	11.7000
	Pb	4	1	76.0000	76.0000	76.0000
	Zn	3	2	94.8000	154.0000	124.4000
SW12004	As	1	1	3.7800	3.7800	3.7800
	Cu	1	1	13.2000	13.2000	13.2000
	Zn	1	1	28.8000	28.8000	28.8000
SW24001	As	2	2	28.7000	38.7000	33.7000
	Zn	2	2	30.9000	150.0000	90.4500
SW24003	As	2	1	2.5600	2.5600	2.5600
	Zn	2	1	162.0000	162.0000	162.0000
SW31002	As	2	1	7.2700	7.2700	7.2700
SW36001	As	2	2	260.0000	380.0000	320.0000
	As[1]	1	1	299.0000	299.0000	299.0000
SW37001	As	6	3	2.7700	9.0400	5.3033
	Cr	6	1	11.5000	11.5000	11.5000
	Zn	6	2	23.2000	29.5000	26.3500

1 = Total Arsenic
μg/l = micrograms per liter

TB1-HIST.SW

Compounds detected at only two sites included the following:

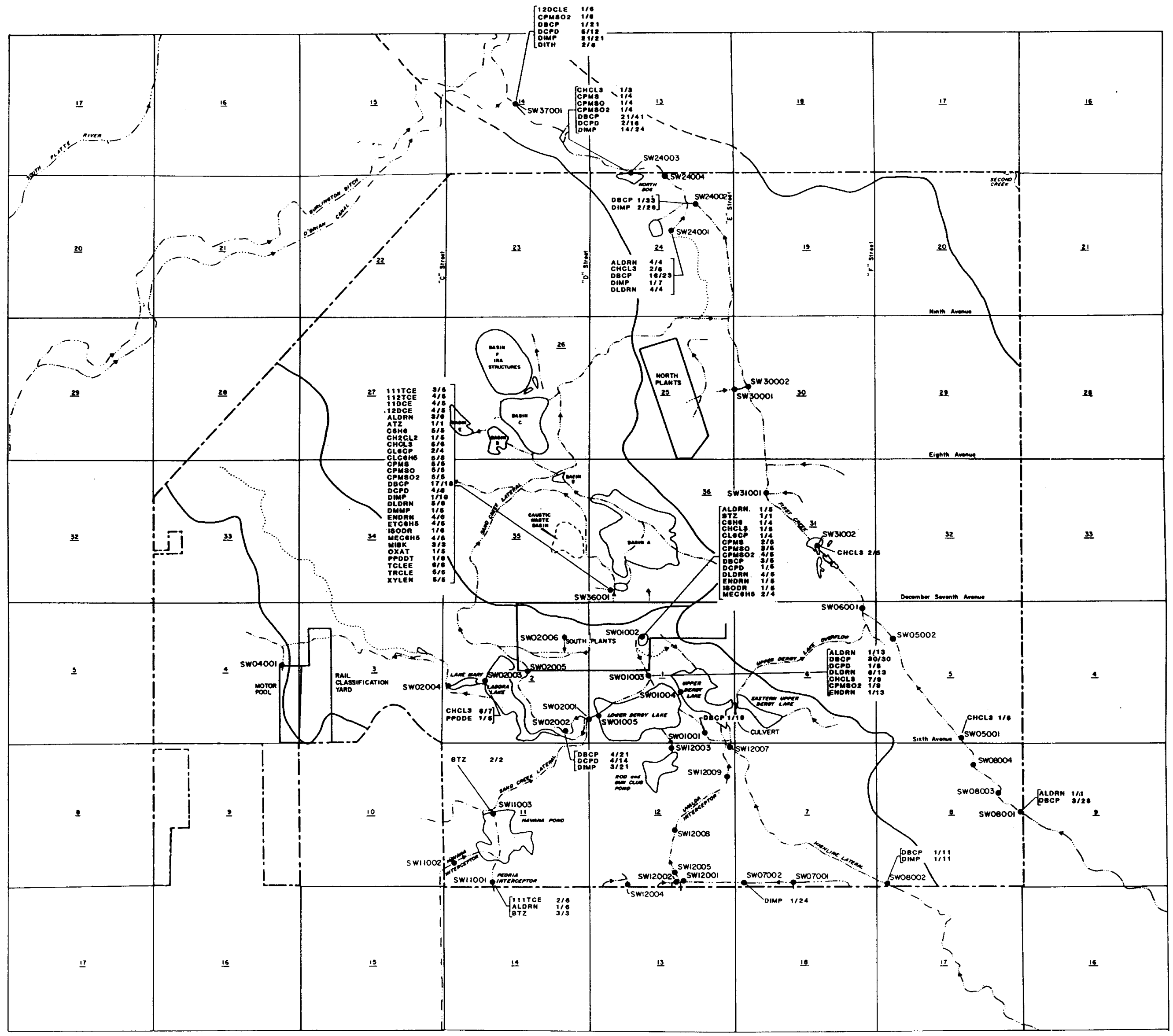
- 1,1,1-Trichloroethane (111TCE)
- Isodrin (ISODRN)
- Toluene (MEC6H5)
- Hexachlorocyclopentadiene (CL6CP)
- Benzene (C6H6)

Compounds detected at only one site included the following:

- 1,1,2-Trichloroethane (112TCE)
- 1,2-Dichloroethane (12DCLE)
- 1,2-Dichloroethene (12DCE)
- Chlorobenzene (CLC6H5)
- Dimethyl methyl phosphonate (DMMP)
- Dithiane (DITH)
- Ethylbenzene (ETC6H5)
- Methylene chloride (CH2CL2)
- Methylisobutylketone (MIBK)
- Oxathiane (OXAT)
- Trichloroethene (TRCLE)
- Xylene (XYLEN)
- Tetrachloroethene (TCLEE)
- 1,1-Dichloroethene (11DCE)
- DDE (PPDDE)
- DDT (PPDDT)

The frequency of historical organic compound detections is provided on Figure 4.3-1, which includes the surface-water sampling location, organic compound, and the frequency at which the compound was detected historically.

As indicated on Figure 4.3-1 and Table 4.3-1, Basin A (SW36001) and the South Plants sedimentation pond site (SW01002) have historical detections of a wide range of compounds, with 28 and 14 compounds detected, respectively. The North Bog (SW24003) and South Plants Ditch monitoring station (SW01003) have historical detections of seven compounds each. The First Creek Off-Post monitoring station



Legend

20 Section Number

Lake, Pond or Basin

Stream or Ditch with Flow Direction

Abandoned Stream or Ditch

SW24001 Surface Water Sample Location

Arsenal Boundary

ALDRN 1/2 1 = Number of Detections
2 = Number of Samples

Drainage Basin Boundary

N

0 2000 4000
FEET

Prepared for:
U.S. Army, Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 4.3-1

Frequency of Historical Target Organic Constituent Detections

CMP SW FY90H

(SW37001) has historical detections of six compounds, and the Sewage Treatment Plant effluent site (SW24001) has historical detections of five compounds.

As indicated in Table 4.3-2, five trace inorganic constituents were detected historically at current CMP surface-water sampling sites. Constituents detected historically at three or more current CMP sites are listed below:

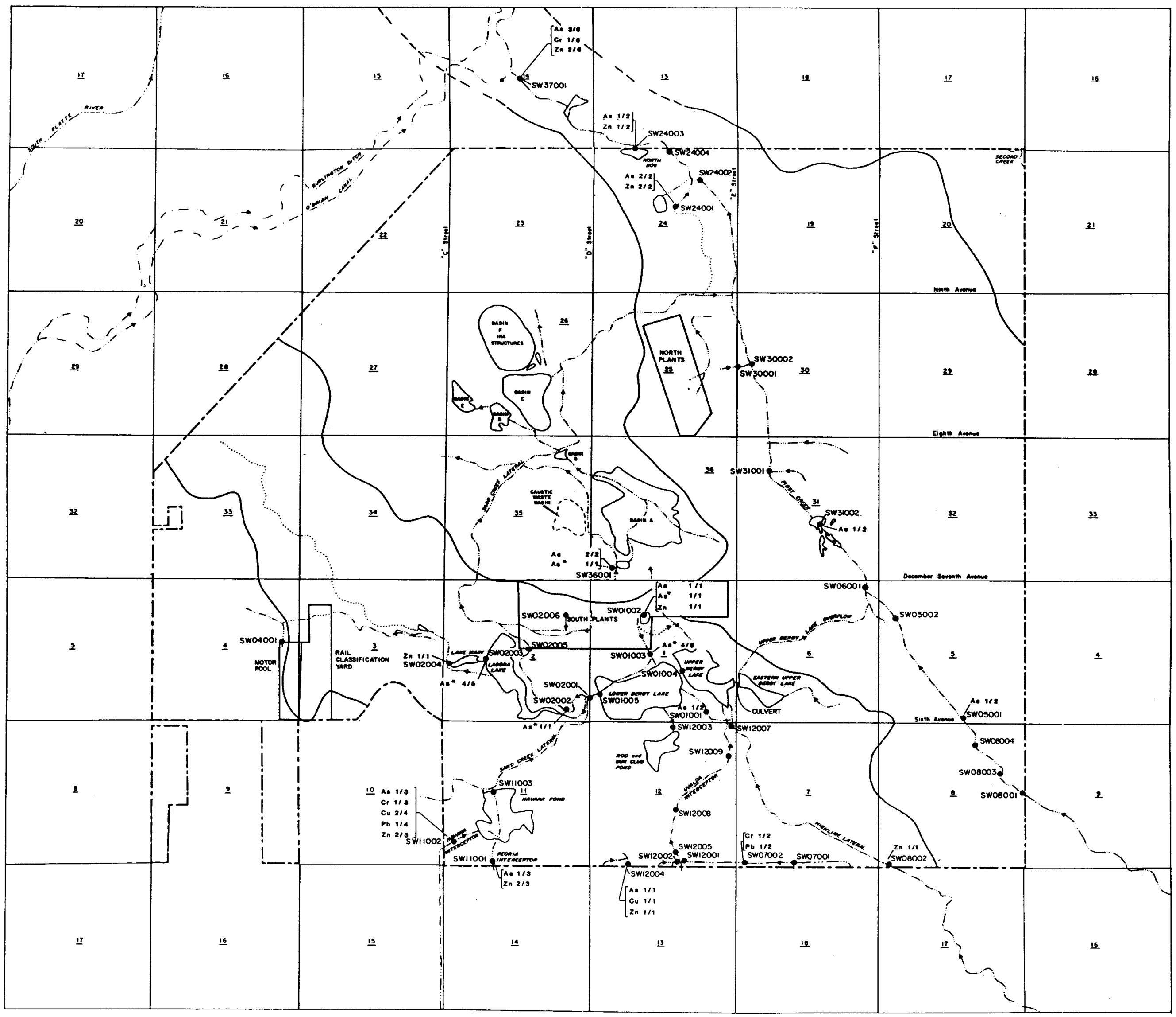
Constituent	No. of Sites
Arsenic (As)	11
Zinc (Zn)	9
Chromium (Cr)	3
Lead (Pb)	2

Copper (Cu) was detected at only two sites.

The frequency of historical metal constituent detections is provided on Figure 4.3-2, which includes the surface-water sampling location, metal constituent, and the frequency at which the constituent was detected historically.

As indicated on Figure 4.3-2, the Havana Interceptor (SW11002) has had historical detections of the widest range of metal constituents, five. All other sites shown on Figure 4.3-2 have historical detections of three or fewer constituents.

The assessment value of the database depends on the quality of its data and the ability to accurately determine previous sampling locations and correlate them with current and future monitoring networks. Management of the database through time — including validating data, ensuring data completeness, and documenting updates and procedures — has been the responsibility of USATHAMA and/or RMA Program Manager's data management contractors. During the CMP, the exact correlation between current CMP sites and the site designations in the database had not been definitely established. In addition, records from previous outstanding monitoring programs have not been included in the database.



Legend

- 20 Section Number
- Lake, Pond or Basin
- Stream or Ditch with Flow Direction
- Abandoned Stream or Ditch
- SW24001 Surface Water Sample Location
- Arsenal Boundary
- As 1/3 — 1 = Number of Detections; 3 = Number of Samples
- Drainage Basin Boundary
- As* Total Arsenic

N

0 2000 4000
FEET

Prepared for:
U.S. Army, Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 4.3-2

Frequency of Historical Trace Inorganic Constituent Detections

CMP SW FY90 H

Comparability of results was assessed by comparing results of the historical analysis presented above to the similar analysis performed for the FY88 report. The primary differences are an increase in the number of samples and/or detections and additional analytes and/or sites. Minor differences occurred in either the number of detections or the minimum/maximum reported for a given site. The differences most likely result from the ongoing effort by DPA to include only validated data in its compilation of the RMA database. Additionally, DPA recalculated all the data to correct the discrepancies that resulted from the use of former IRDMIS software programs (James Clark, DPA, personal communication 1989).

4.3.2 SUMMARY OF PREVIOUS RMA SURFACE-WATER QUALITY INVESTIGATION FINDINGS

This section provides a summary and assessment of previous RMA surface-water quality investigations. Surface-water quality data have been collected at RMA under many programs and tasks. This section summarizes the results of and conclusions drawn from major pre-CMP data-collection programs.

4.3.2.1 360 Degree Monitoring Program

The 360 Degree Monitoring Program was initiated in 1975 primarily to monitor on-post and off-post groundwater quality. Initially, the program included 12 on-post and 10 off-post surface-water locations. In 1983, 17 surface-water sites were sampled quarterly, and data collection activities were summarized in periodic data summaries (Ward, 1984). Most of the data collected under the program from 1979 to 1985 were incorporated into a computer database, which is discussed further in Section 1.3.2.6.

4.3.2.2 Remedial Investigation Studies

In 1984, the RMA RI/FS was initiated. Sampling formerly conducted under the 360 Degree Monitoring Program was incorporated into several RI tasks. From 1985 to 1987, surface-water quality data were collected in conjunction with four RI tasks (Ebasco, et al., 1989a). Sixteen surface-water sites were sampled under a regional groundwater monitoring program (Task 4) from October 1985 to March 1986. As part of Task 4, 19 and 21 surface-water sites were sampled during the third and fourth quarters of FY86, respectively. A review of the distribution of analytes detected at the RMA surface-water sites used during the program showed surface-water contamination occurred primarily in the South Plants - Basin A area (ESE, 1988a). Organochlorine pesticides, purgeables, organosulfur compounds, DBCP, and DCPD were detected in samples collected from surface-water sampling sites in this area for both the third

and fourth quarter sampling analyses. Dieldrin, DIMP, DCPD, and dithiane were detected in samples collected at off-post site 14BDD (Figure 3.3-1) (ESE, 1988a). From December 1986 through September 1987, 11 sites were sampled under Task 39, the off-post RI. DIMP and aldrin were detected in an upstream sample collected from First Creek (08ADD, Figure 3.3-1). DIMP, dieldrin, and aldrin were detected in a sample collected where First Creek exits RMA at the north boundary (13DCC, Figure 3.3-1). DCPD, DIMP, 1,4-diathiane, CPMSO2, 1,2-dichloroethane and dieldrin were detected at concentrations exceeding CRLs in samples from First Creek at Highway 2 (14BDD, Figure 3.3-1). Inorganic constituents included elevated chloride, fluorine and sulfate concentrations from First Creek at Highway 2. Available data indicated that contaminated groundwater discharged off-post was the primary source of the off-post First Creek contamination (ESE; August, 1988e). As part of the Task 44 regional monitoring program, 41 on-post and off-post surface-water sites were sampled from October 1986 to August 1987. No final data assessment report was prepared as part of Task 44 to document the program's results. Sampling results and an overall assessment of data gathered during Tasks 4, 39, and 44 were presented in the WRI Report (Ebasco, et al., 1989a).

4.3.2.3 Remedial Investigation Documentation

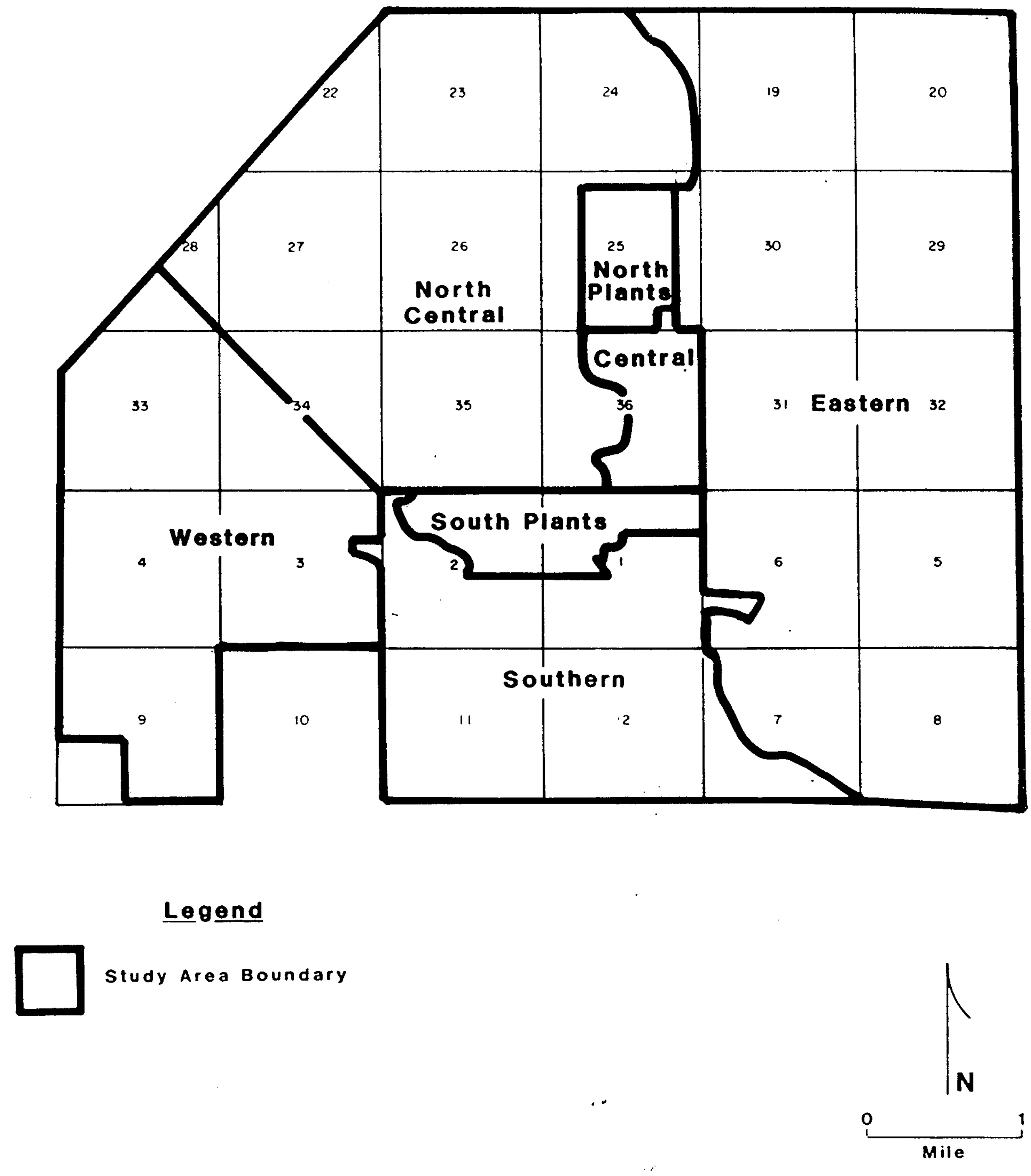
Final documentation of the overall RI of RMA was being prepared in accordance with the proposed Federal Facility Agreement and Settlement Agreement (1988), the RMA Technical Program Plan (PMO, TPP, 1988/RIC 88131R01), and applicable RI guidance comments. Table 4.3-3 lists the reports that constitute the RI, including an overview report; reports for air, water, building, and biota media; and seven study area reports (SARs). These reports are intended to define the nature and extent of contamination for the On-Post Operable Unit of RMA as required by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), as amended, and the National Contingency Plan (NCP). Key findings and conclusions presented in these reports are summarized herein as they pertain to existing and/or potential surface-water contamination at RMA.

The WRIR (Ebasco, et al., 1989a) represents the most recent comprehensive assessment of the RMA surface-water system. The water-quality sampling network and data used to prepare the WRI Report were generated by Tasks 4, 39, and 44. Tabular summaries of the results of previous surface-water investigations, including sampling locations, and analytical results from fall 1985 through fall 1987 were included in the WRI Report. Data generated from the WRI were used in detailed contamination assessments of each of the seven RMA study areas. Figure 4.3-3 shows the locations of the seven RMA

Table 4.3-3 RMA Remedial Investigations and Study Area Reports

Report	Volume
Overview of RMA Remedial Investigations and Study Area Reports	I
Water Remedial Investigation Report	II
Air Remedial Investigation Report	III
Biota Remedial Investigation Report	IV
Summary of Results Structures Survey Report Structure Profiles Structures Survey Report Databases Structures Survey Report	V
Southern Study Area Report	VI
Eastern Study Area Report	VII
South Plants Study Area Report	VIII
North Plants Study Area Report	IX
Central Study Area Report	X
North Central Study Area Report	XI
Western Study Area Report	XII

Source: Ebasco Services, Inc., et.al, 1989g



Source: Ebasco, 1989

Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup
Commerce City, Colorado

FIGURE 4.3-3
Locations of Study Areas

Rocky Mountain Arsenal

Prepared by: R.L. Stollar & Associates, Inc.
CMP SW FY90 H

study areas. Conclusions relating to surface-water quality from each of the SARs are summarized in the following section.

4.3.2.4 Summary of Key Remedial Investigation Findings

4.3.2.4.1 Southern Study Area

According to the Southern SAR (Ebasco, et al., 1989b), surface-water is the principal migration pathway for organochlorine pesticides, DBCP, arsenic, mercury, and ICP metals in this study area. Volatile halogenated organics, volatile aromatic organics, and organochlorine pesticides were also detected in samples of surface-water from ditches originating in the South Plants and from ditches entering RMA from the Montbello industrial and residential area to the south. Several drainage ditches from South Plants were reported to be discharging sediment in runoff containing volatile aromatic organics, semivolatile halogenated organics, organochlorine pesticides, arsenic, mercury, and ICP metals.

4.3.2.4.2 South Plants Study Area

The South Plants Area is located on a topographic high, and surface-water in this area is described in the South Plants SAR (Ebasco, et al., 1989c) as either locally ponded or exiting the area via a complex system of drainage ditches and storm drains. Classes of compounds detected in surface-water during the RI included volatile halogenated organics, volatile hydrocarbons, volatile aromatic organic compounds, herbicide-related organosulfur compounds, GB-agent related organophosphorus compounds, DBCP, semivolatile halogenated organics, and organochlorine pesticides. The SAR documented the conclusion that surface water is a significant transport mechanism for contaminants in the South Plants Study Area.

4.3.2.4.3 Eastern Study Area

Surface-water was identified as a potential migration pathway for contaminants in the Eastern Study Area (Ebasco, et al., 1989h). According to the SAR, man-made drainages, several of which drain into First Creek, are located sporadically throughout this study area. Because of these source areas, surface runoff during storms could carry both dissolved and suspended contaminants into First Creek. However, results from analysis of surface-water and ditch sediment samples during the RI indicated that impacts to surface water derived from activities in the Eastern Study Area are minimal (Ebasco, et al., 1989h).

4.3.2.4.4 Central Study Area

The Central Study Area is described in the SAR (Ebasco, et al., 1989e) as a highland area with no standing water bodies. According to this report, any surface-water runoff from this area either evaporates or infiltrates before leaving the boundaries of the study area. The report indicates that surface water and wind have historically dispersed primarily organochlorine pesticides, arsenic, and mercury from sources in other study areas, such as Basin A, to surface soils in the southwestern two-thirds of the Central Study Area. However, surface water is not currently a potential migration pathway in the Central Study Area.

4.3.2.4.5 North Plants Study Area

According to the North Plants SAR (Ebasco, et al., 1989d), surface water generally flows east to northeast in this area and is usually confined to numerous man-made ditches. Nontarget polyaromatic hydrocarbons were tentatively identified in samples of surface soils and a main drainage; therefore, suspended and bed load sediments in surface water were identified in the SAR as transport mechanisms for this class of compounds. The SAR also indicated that surface-water transport and windblown dust would be the primary transport mechanisms for arsenic, mercury, and ICP metals.

4.3.2.4.6 North-Central Study Area

According to the North-Central SAR (Ebasco, et al., 1989f), the history of the sites in this study area indicates that surface drainage was a significant transport mechanism for potential contaminants. This study area contains Basins A, B, C, and D. The SAR reported that surface-water samples from Basin A have consistently contained organochlorine pesticides, herbicide-related organosulfur compounds, and arsenic derived from leaching of surficial soils by runoff. According to the SAR, surface-water samples from the North Bog and First Creek (where it exits RMA) collected during the RI did not yield potential contaminants, which indicated that these water bodies are not active mechanisms for transport offpost. The SAR reported that samples of surface-water entering the North-Central Study Area from the South Plants Study Area have consistently contained high concentrations of volatile halogenated organics, volatile aromatic organics, volatile hydrocarbons, mustard agent-related organosulfur compounds, DBCP, organochlorine pesticides, and arsenic but that this surface water is generally contained within the basins' drainage network and does not exit RMA.

4.3.2.4.7 Western Study Area

According to the Western SAR (Ebasco, et al., 1989g), surface-water does not occur in this study area except as brief episodes of runoff following excessive precipitation. Comprehensive surface-water programs have not been conducted in this study area, and the SAR supports the conclusion that surface-water is not thought to be a primary migration pathway for contaminants in this study area.

4.4 CMP Surface-Water Quality Assessment

This section assesses trends displayed in WY88 and WY89 surface-water quality results. Mechanisms for the distribution and concentrations of chemical constituents in surface-water and stream sediments are diverse and can complicate interpretation of data.

Large-scale spatial variations in concentrations of chemical constituents can result from varying physical factors along a stream reach. Factors affecting large-scale spatial variations in concentrations of organic constituents include proximity to contaminant source areas and chemical degradation/transformation as a function of exposure to sunlight and biological mechanisms. Small scale variations can occur within a channel cross section as a function of depth and flow velocity

Temporal variations in concentrations of chemical constituents at a given location can occur as a function of discharge, bed load transport, changes in baseflow chemistry, deposition of wind-borne particulates in the channel and/or washing of these particulates into the reach during storms and seasonal environmental fluctuations (e.g., temperature).

A third physical condition affecting concentrations (not depicted) would involve wind-borne deposition of particulates directly into the channel, causing fluctuations in chemical concentrations independent of discharge.

With respect to data assessment, surface water must be considered a dynamic system capable of producing wide fluctuations in concentrations of chemical constituents, both temporally and spatially. Current data often must be assessed along with corresponding discharge data and historical chemical/discharge data to recognize the physical and chemical mechanisms influencing contaminant detections and water chemistry at a given location.

4.4.1 Fiscal Year 1988 CMP Results

Table 4.4-1 and Table 4.4-2 summarize organic compound and metal detections at CMP surface-water sampling sites during the first 2 years of the program. Results from individual years of the program are provided in the following sections. During FY88, 29 surface-water quality locations were sampled and analyzed for 39 organic compounds. During the spring the site with the most organic compound detections was SW36001 (Basin A monitoring station) with 16 detections followed by SW01002 (South Plants water tower pond) with 11 detections. The most common organic compounds detected during FY88 are listed below:

- dieldrin (DLDRN - 5 sites
- chloroform (CHCL3) - 4 sites
- volatile aromatic compounds (BETX) - 4 sites
- hexachlorocyclopentadiene (CL6CP) - 4 sites
- dicyclopentadiene (DCPD) - 3 sites

The most common inorganic detections, listed in order of number of sites detected, were:

- zinc (total) -- 33 sites
- mercury (total) -- 31 sites
- lead (total) -- 31 sites
- arsenic (total) -- sites

4.4.1.1 Surface-Water Target Organic Compounds

Detections of surface-water target organic compounds during FY88 are listed on Table 4.4-1. About 85 percent of the detections were in samples from Basin A (SW36001) and the South Plants water tower pond (SW01002). Of the 39 target list organic compounds, the following were not detected in samples from any of the surface-water sites: 1,1-dichloroethane ($C_2H_4Cl_2$), 1,2-dichloroethane ($C_2H_4Cl_2$), m-xylene (C_8H_{10}), carbon tetrachloride (CCl_4), chlordane ($C_{10}H_6Cl_8$), dimethyl disulfide ($C_2H_6S_2$), dithiane ($C_4H_8S_2$), Isodrin ($C_{12}H_8Cl_6$), methylene chloride (CH_2Cl_2), oxathiane (C_4H_8SO), and dimethyl methyl phosphonate.

Table 4.4-1 Detections of Organic Compounds During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 1 of 4)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW01001	DMMP	3	1	1.0300	1.0300	1.0300
SW01002	11DCE	2	1	3.1900	3.1900	3.1900
	ALDRN	2	2	3.2000	4.3000	3.7500
	ATZ	1	1	85.2000	85.2000	85.2000
	BTZ	2	1	14.2000	14.2000	14.2000
	CHCL3	2	2	3.3900	7.0700	5.2300
	CL6CP	2	1	0.2210	0.2210	0.2210
	CLDAN	2	1	9.9000	9.9000	9.9000
	CPMSO	2	1	750.0000	750.0000	750.0000
	CPMSO2	2	2	9.4000	84.0000	46.7000
	DBCP	2	2	2.6900	38.0000	20.3450
	DCPD	2	2	15.6000	96.9000	56.2500
	DLDRN	2	2	2.0000	3.8000	2.9000
	DMMP	2	1	0.7420	0.7420	0.7420
	ENDRN	2	2	0.4700	2.7000	1.5850
	ISODR	2	1	0.7400	0.7400	0.7400
	MEC6H5	2	1	4.4200	4.4200	4.4200
	MLTHN	1	1	10.7000	10.7000	10.7000
	PPDDE	2	1	4.2000	4.2000	4.2000
	PPDDT	2	2	0.1930	4.8000	2.4965
	PRTHN	1	1	15.1000	15.1000	15.1000
	SUPONA	1	1	7.1000	7.1000	7.1000
	TCLEE	2	1	1.6400	1.6400	1.6400
	XYLEN	2	1	3.3000	3.3000	3.3000
SW01004	DLDRN	1	1	0.0493	0.0493	0.0493
	ENDRN	1	1	0.0533	0.0533	0.0533
SW02004	ISODR	1	1	0.0972	0.0972	0.0972
SW02006	CHCL3	3	3	3.0000	4.3300	3.8633
	DMMP	3	1	2.5400	2.5400	2.5400
SW04001	DLDRN	1	1	0.0551	0.0551	0.0551
SW05005	DLDRN	1	1	0.0946	0.0946	0.0946
SW06006	CHCL3	1	1	0.9480	0.9480	0.9480
	DLDRN	1	1	0.0595	0.0595	0.0595
SW07001	ALDRN	4	1	0.1520	0.1520	0.1520
	CL6CP	4	1	0.0717	0.0717	0.0717
	DDVP	2	1	1.8600	1.8600	1.8600
	DLDRN	4	1	0.0795	0.0795	0.0795
	DMMP	3	1	2.0800	2.0800	2.0800
	ISODR	4	1	0.1320	0.1320	0.1320
	PPDDE	4	1	0.2520	0.2520	0.2520
	PPDDT	4	1	0.0638	0.0638	0.0638
SW07002	DIMP	2	1	0.6410	0.6410	0.6410

Table 4.4-1 Detections of Organic Compounds During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 2 of 4)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW08001	DDVP	1	1	0.7880	0.7880	0.7880
SW08003	DBCP	6	1	0.2410	0.2410	0.2410
	DLDRN	6	1	0.0621	0.0621	0.0621
	ENDRN	6	1	0.0625	0.0625	0.0625
SW11001	BTZ	6	1	34.3000	34.3000	34.3000
	CL6CP	10	1	0.7100	0.7100	0.7100
	PRTHN	7	1	1.0400	1.0400	1.0400
	XYLEN	12	1	1.4600	1.4600	1.4600
SW11002	BTZ	7	1	9.3400	9.3400	9.3400
	CL6CP	12	2	0.2590	3.3000	1.7795
	DMMP	10	1	0.4300	0.4300	0.4300
SW11003	ALDRN	4	1	0.0581	0.0581	0.0581
	CLDAN	4	1	0.1490	0.1490	0.1490
	CPMSO	6	1	32.7000	32.7000	32.7000
	CPMSO2	6	1	100.0000	100.0000	100.0000
	DDVP	2	1	0.7270	0.7270	0.7270
	PPDDT	4	1	0.0552	0.0552	0.0552
SW12003	ENDRN	1	1	0.0588	0.0588	0.0588
SW12004	ATZ	3	1	4.2800	4.2800	4.2800
	CPMSO	5	1	35.9000	35.9000	35.9000
	DDVP	3	1	0.7030	0.7030	0.7030
SW12005	C6H6	11	1	3.0300	3.0300	3.0300
	CHCL3	10	1	0.8800	0.8800	0.8800
	CL6CP	9	1	0.8300	0.8300	0.8300
	TCLEE	10	1	2.6600	2.6600	2.6600
	TRCLE	10	1	7.5200	7.5200	7.5200
SW24001	DMMP	6	1	0.5080	0.5080	0.5080
SW24002	DDVP	3	1	0.6600	0.6600	0.6600
	TRCLE	3	1	35.5000	35.5000	35.5000
SW24003	DDVP	1	1	0.6350	0.6350	0.6350
	DIMP	2	1	2.0600	2.0600	2.0600
SW30002	DDVP	1	1	0.6350	0.6350	0.6350
SW36001	111TCE	6	2	1.9700	2.6300	2.300
	112TCE	6	4	0.9690	12.0000	6.8923
	11DCE	6	2	4.6000	10.8000	7.7000
	12DCE	6	4	8.2000	73.0000	31.6500
	13DMB	6	1	180.0000	180.0000	180.0000
	ALDRN	5	3	1.6000	13.0000	7.0333

Table 4.4-1 Detections of Organic Compounds During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 3 of 4)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (µg/l) Minimum	Maximum	Average
SW36001	ATZ	4	4	6.1700	370.0000	105.1575
	BCHPD	4	3	10.9000	53.4000	36.1000
	C6H6	6	4	18.6000	360.0000	148.6500
	CHCL3	6	6	76.0000	940.0000	332.3333
	CL6CP	5	3	0.6730	2.6000	1.4243
	CLC6H5	6	6	150.0000	7500.0000	1590.5000
	CLDAN	5	2	8.6000	64.0000	36.3000
	CPMS	6	4	12.6000	120.0000	53.4000
	CPMSO	6	4	24.0000	73.7000	40.7000
	CPMSO2	6	4	130.0000	1600.0000	757.5000
	DBCP	6	5	6.2300	130.0000	61.6060
	DCLB	2	2	290.0000	300.0000	295.0000
	DCPD	6	5	11.2000	76.7000	37.3600
	DDBVP	4	2	6.2900	57.0000	31.6450
	DIMP	5	2	0.4960	4.1300	2.3130
	DITH	6	1	1.5800	1.5800	1.5800
	DLDRN	5	3	2.8000	6.5000	4.7000
	DMDS	4	1	1.8200	1.8200	1.8200
	DMMP	5	2	1.7000	10.8000	6.2500
	ENDRN	5	3	0.6800	3.7000	2.2267
	ETC6H5	6	5	27.0000	310.0000	117.0400
	ISODR	5	2	0.4550	1.6000	1.0275
	MEC6H5	6	4	5.7900	140.0000	48.3175
	MIBK	6	4	8.7700	3200.0000	1202.1925
	PPDDE	5	2	0.2600	0.8990	0.5795
	PPDDT	5	2	0.5080	2.8000	1.6540
	PRTHN	4	1	50.0000	50.0000	50.0000
	SUPONA	4	3	1.9100	16.3000	7.5500
	TCLEE	6	6	4.4700	340.0000	124.4617
	TRCLE	6	5	10.0000	270.0000	89.4000
	XYLEN	6	6	32.7000	520.0000	195.1500
SW37001	ATZ	1	1	9.5900	9.5900	9.5900
	CLDAN	2	1	0.2680	0.2680	0.2680
	DCPD	2	2	9.9100	21.1000	15.5050
	DIMP	2	2	88.0000	135.0000	111.5000
	DLDRN	2	2	0.0577	6.7000	3.3789
	ENDRN	2	1	0.0643	0.0643	0.0643
	PPDDT	2	1	0.0571	0.0571	0.0571
SW37002	DIMP	2	1	4.9200	4.9200	4.9200
	DMMP	2	1	0.2270	0.2270	0.2270
SW37003	DIMP	2	1	5.9000	5.9000	5.9000
	DLDRN	2	1	0.1470	0.1470	0.1470
	DMMP	2	1	0.2380	0.2380	0.2380
SW37004	CPMSO2	2	1	19.4000	19.4000	19.4000
	DIMP	2	1	6.1100	6.1100	6.1100
	DITH	2	1	44.2000	44.2000	44.2000
	DMMP	2	1	0.2570	0.2570	0.2570

Table 4.4-1 Detections of Organic Compounds During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 4 of 4)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (μg/l) Minimum	Maximum	Average
SW37006	CPMSO	2	1	1200.0000	1200.0000	1200.0000
	CPMSO2	2	1	170.0000	170.0000	170.0000
	DIMP	2	1	4.7600	4.7600	4.7600
	DLDRN	2	1	0.0764	0.0764	0.0764
	DMMP	2	1	0.2510	0.2510	0.2510
SW37007	DIMP	1	1	13.1000	13.1000	13.1000
	DMMP	1	1	4.9200	4.9200	4.9200

μg/l = micrograms per liter

Table 4.4-2 Detections of Trace Inorganics During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 1 of 2)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (μg/l) Minimum	Maximum	Average
SW01001	Zn	5	1	23.8000	23.8000	23.8000
SW01002	As	3	3	7.4400	19.4000	14.5800
	Hg	3	3	0.1640	0.2300	0.1973
	Zn	3	1	34.8000	34.8000	34.8000
SW01004	As	4	2	2.4400	2.6100	2.5250
SW02003	Hg	4	2	0.1580	0.2150	0.1865
SW02004	As	4	2	3.4500	3.7700	3.6100
SW02006	As	3	1	2.6400	2.6400	2.6400
	Hg	3	3	0.1030	0.2940	0.1767
SW04001	Zn	1	1	43.7000	43.7000	43.7000
SW06006	Hg	2	1	0.2000	0.2000	0.2000
SW07001	Hg	7	1	0.2010	0.2010	0.2010
	Zn	7	2	52.7000	68.8000	60.7500
SW07002	As	5	1	2.6400	2.6400	2.6400
SW08001	As	2	1	2.6100	2.6100	2.6100
SW08002	Pb	2	1	77.0000	77.0000	77.0000
SW08003	As	6	1	2.8300	2.8300	2.8300
SW11001	As	10	2	4.7400	5.9300	5.3350
	Zn	10	5	30.2000	168.0000	77.5800
SW11002	Cu	12	1	10.5000	10.5000	10.5000
	Zn	8	4	29.4000	190.0000	94.1250
SW11003	Zn	8	1	126.0000	126.0000	126.0000
SW12001	Cyn	2	1	6.9100	6.9100	6.9100
	Zn	3	1	45.7000	45.7000	45.7000
SW12003	As	2	2	2.7700	3.1100	2.9400
	Zn	2	1	36.9000	36.9000	36.9000
SW12004	Zn	7	4	23.5000	87.3000	42.3750
SW12005	As	12	1	2.4300	2.4300	2.4300
	Hg	12	2	0.2290	0.2570	0.2430
	Zn	10	3	27.3000	64.4000	42.7667
SW24001	As	6	5	3.9900	30.2000	23.0380

TB1-HIST.SW

Table 4.4-2 Detections of Trace Inorganics During FY88 and FY89 at CMP Surface-Water Sampling Sites (Page 2 of 2)

CMP Site	Analyte	No. of Samples	No. of Detections	Concentration (μg/l) Minimum	Maximum	Average
SW24002	As	5	2	3.9900	4.7400	4.3650
	Hg	5	1	0.3100	0.3100	0.3100
SW30002	As	3	1	3.1300	3.1300	3.1300
SW31002	As	6	4	3.2300	4.3100	3.8525
SW36001	As	7	7	118.0000	440.0000	254.0000
	Cd	7	2	13.5000	14.9000	14.2000
	Hg	7	1	0.2360	0.2360	.2360
	Zn	5	1	32.7000	32.7000	32.7000
SW37001	As	4	2	5.1700	5.3900	5.2800
	Hg	4	2	0.2300	0.3790	0.3045
SW70002	As	1	1	280.0000	280.0000	280.0000
	Cyn	1	1	12.3000	12.3000	12.3000
	Zn	1	1	93.3000	96.3000	93.3000
SW37003	Zn	1	1	33.6000	33.6000	33.6000
SW37004	As	1	1	4.5500	4.5500	4.5500
SW37006	As	1	1	5.2700	5.2700	5.2700
SW37007	As	1	1	20.9000	20.9000	20.9000

μg/l = micrograms per liter

4.4.1.2 GC/MS Detections

GC/MS analysis confirmed CMP surface-water target list compound analyses and provided information on 22 additional (nontarget) compounds. Detections of these additional compounds were limited to three GC/MS results for a sample collected near Basin A (SW36001) on October 4, 1988. The compounds detected were 1,4-dichlorobenzene (>300 μg/l), atrazine (36.4 μg/l), and supona (16.3 μg/l).

4.4.1.3 Trace Inorganic Constituents

Trace constituents for which analyses were performed include arsenic, cadmium, chromium, copper, lead, mercury, and zinc. The detections of these constituents are presented in Table 4.4-2.

Arsenic was detected at 15 sites, with the highest concentration of 440 μg/l reported for a sample from Basin A (SW36001). The next highest values were detected in several locations along the northern boundary in the First Creek drainage. In general, the highest zinc concentrations were detected near the southern boundary of RMA with the highest detections associated with the Havana and Peoria Interceptor monitoring stations. Mercury was detected at six sites, with all reported detections less than or equal to 0.379 μg/l. Lead was reported for only one sample, from the Highline Lateral South Boundary (SW08002) at a concentration of 77 μg/l. Cadmium, chromium, and copper were not detected above their respective CRLs.

4.4.1.4 Major Inorganic Constituents

The major inorganic constituents for which analyses were performed include calcium, magnesium, sodium, sulfate, nitrogen, potassium, and fluoride. Seven of the eight highest reported values for each constituent were detected in First Creek Off-Post monitoring locations (SW37001 and SW37002). The other area of high concentration (potassium) was the South Plants water tower pond (SW01002). The low values for most of the major inorganic constituents were reported for samples from the upgradient southern boundary, specifically the Peoria Interceptor monitoring station (SW11001).

4.4.2 Fiscal Year 1989 CMP Results

During FY89 organic compounds were detected at 21 of 30 sites. The sites with the most organic compound detections during the spring were SW36001 (Basin A) with 37, and SW01002 (South Plants water tower pond) with 20. The most common organic compounds are listed below:

- vapona -- 7 sites
- dimethylmethylphosphonate (DMMP) -- 6 sites
- endrin -- 6 sites
- dieldrin -- 5 sites
- hexachlorocyclopentadiene (CL6CP) -- 5 sites
- p,p′-DDE (PPDDT) -- 5 sites
- aldrin, DIMP, chlordane, isodrin -- 4 sites

During FY89 the most common inorganic detections were:

- zinc (total) -- 10 sites
- arsenic (total) -- 10 sites
- mercury (total) -- 4 sites

Seven high (storm) event samples were collected during FY89 at locations along the southern boundary and at interior locations that normally do not display surface-water. Organic compounds were detected at SW11001 (Peoria Interceptor), SW08003 (South First Creek) and SW04001 (Motor Pool). At SW11001 2,4,5 trichlorophenol, parathion and xylene (o,p) were detected. In the sample obtained from SW08003, DBCP was detected. At SW04001, dieldrin was detected. Inorganic compounds were detected at SW12005 (South Uvalda), SW11001 and SW11002 (Havana Interceptor). Zinc was detected during storms at SW12005, SW11001 and SW11002. Copper was detected at SW11002 during a storm.

4.4.2.1 Surface-Water Target Organic Compounds

Surface-water detections of target organic compounds during FY89 are listed in Table 4.4-1. Forty-one organic compounds were detected on the Arsenal, of which 90 percent were found in samples from Basin A (SW36001). The South Plant's Water Tower Pond (SW01002) followed at 49 percent. Of the 57

target organic compounds on the list, 16 were not detected in any of the surface-water site samples. These include: 1,1-dichloroethane, 1,1-dichloroethene, 1,1,1-trichloroethane, 1,2-dichlorethane, carbon tetrachloride, methylene chloride, tetrachloroethene, 1,4-oxathiane, 2-methylphenol (2-cresol), 2-nitrophenol, 2,4-dimethylphenol, 2,4-dinitrophenol, 2,4,6-trichlorophenol, 4-chloro-3-cresol(3-methyl-4-chlorophenol), 4-nitrophenol, and pentachlorophenol.

4.4.2.2 GC/MS Detections

GC/MS analysis confirmed CMP target compound analyses and provided information on potential nontarget compounds that may have been present at specific locations. There were 23 additional nontarget organic compounds detected at four sites during spring, fall and storm sampling events (Table 4.2-3).

4.4.2.3 Trace Inorganic Constituents

The FY89 CMP study analyzed for six metals, arsenic and cyanide. The metals were cadmium, chromium, copper, lead, mercury and zinc, of which chromium and lead were not detected in any samples, and copper was detected in one storm sample from Havana Interceptor (SW11002). Arsenic was detected in all First Creek samples; whereas, zinc was a common contaminant in the Irondale Gulch drainage basin.

4.4.2.4 Major Inorganic Constituents

The major inorganic constituents for which analyses were performed are calcium, chloride, fluoride, potassium, magnesium, sodium, nitrate-nitrite and sulfate. The Irondale Gulch drainage sites contained 90 percent of the minimum concentrations for major inorganic constituents; whereas, the First Creek drainage basin had the majority of sites with maximum concentrations for major inorganic constituents during spring and storm sampling. Uvalda Ditch sampling site (SW12002) contained two-thirds of the storm samples representing maximum concentrations of major inorganic constituents.

4.5 PRE-CMP STREAM SEDIMENT SAMPLING ASSESSMENT

Stream bottom sediment samples were collected at 11 locations around RMA as part of the RMA Off-Post Contaminant Assessment Investigation (ESE, 1987c). Three of the sample sites were located on First Creek. Sample location 14BDD corresponds to CMP sampling site SW37001 (Figure 3.3-1, Table 3.3-1). Sample location 08ADD corresponds to CMP sample site SW08001 (Figure 3.3-1, Table 3.3-1). The third sediment sampling location on First Creek, 13DCC, was located just north of 96th Avenue. None of the samples exhibited organic contaminant concentrations exceeding the CRLs. Several metals exceeded CRLs (Table 4.5-1). The remaining sampling locations were off-post sites on the South Platte River, Burlington Ditch, O'Brian Canal, Second Creek, and Barr Lake.

Surface-water bottom sediment samples were collected on First Creek Off-Post at three locations as part of the Off-Post RI/FS (ESE, 1988e). These locations were: site FC2S, about 20 ft downstream of the culvert passing under Highway 2; site FCIS, west of Peoria Street; and site FC1S, which corresponds to sampling location 13DCC (Figure 3.3-1, Table 3.3-1). Other sediment samples were collected at three locations along O'Brian Canal and three locations in Barr Lake. Analytical results of the First Creek off-post sediment sampling program are presented on Table 4.5-2 and Table 4.5-3. Dieldrin was the only organic contaminant detected in the First Creek sediment samples (FC1S, 0.006 $\mu g/g$). Several metals exceeded the CRLs. Metal concentrations were lower in First Creek samples than in O'Brian Canal samples by an average factor of 3. Metal concentrations in First Creek were generally slightly higher, except for lead, than those samples collected previously. The higher values may have partly been the result of the collection of smaller particles (ESE, 1988e).

4.6 CMP SEDIMENT TRANSPORT DATA ASSESSMENT

4.6.1 SEDIMENT QUANTITY

4.6.1.1 FY88 Sediment Quantity Sampling Results

A preliminary study was initiated in October 1988 to obtain information on the volume of suspended sediments in First Creek from Sections 8, 5 and 6. The locations of these samples (SW08001, SW05002, and SW06001) are shown in Figure 3.2-2. The suspended sediment samples were collected using a DH-48. The sample was collected at each site over a period of 30 minutes. Instantaneous discharges were

Table 4.5-1 Metal Concentrations in Off-Post Sediment ($\mu g/g$)

Analyte	Sampling Locations 14BDD	13DCC	08ADD
Cadmium	<0.900	<0.900	<0.900
Chromium	10.2	11.2	9.7
Copper	6.48	9.45	<4.80
Lead	25.1	24.0	<17.0
Zinc	39.6	43.1	43.9
Arsenic	<4.70	<4.70	<4.70
Mercury	<0.05	<0.05	<0.05

From ESE, 1987

Table 4.5-2 Bottom Sediment Analyses for Organic Constituents (April 14, 1988) ($\mu g/g$)

	SITE NUMBER		
Analyte	FC1S	FC2S	FCLS
HCPD	<.003	<.003	<.003
Aldrin	<.002	<.002	<.002
Isodrin	<.001	<.001	<.001
p,p'DDE	<.001	<.001	<.001
Dieldrin	.006	<.012	<.001
p,p'DDT	<.002	<.002	<.002
CLDANE	<.111	<.111	<.111
DMDS	<.692	<.692	<.692
OXATH	<.856	<.865	<.865
DITH	<.571	<.571	<.571
CPMS	<1.08	<1.08	<1.08
BTZ	<1.08	<1.08	<1.08
CPMSO	<2.25	<2.25	<2.25
CPMSO2	<2.87	<2.87	<2.87
DBCP	<.005	<.005	<.005
DIMP	<.114	<.114	<.571
DMMP	<.133	<.133	<1.08

From ESE (1988)

Table 4.5-3 Bottom Sediment Analyses for Metals (April 14, 1988) ($\mu g/g$)

Analyte	SITE NUMBER FC1S	FC2S	FCLS
Cadmium	<.921	<.921	<.921
Chromium	15.4	<7.16	40.6
Copper	17.3	8.86	35
Lead	<16.8	<16.8	<16.8
Zinc	66.1	43.1	145
Arsenic	<4.7	<4.7	<4.7
Mercury	<.05	<.05	<.05

From ESE (1988)

measured at each site using a Pygmy meter (SW08001) and a Baski flume (SW05002 and SW06001). The measured flow rates were 0.37 cfs at SW08001, 0.33 cfs at SW05002, and 0.05 cfs at SW06001. The total suspended solids (TSS) collected and quantified by DataChem Laboratories were 170 mg/L at SW08001, 410 mg/L at SW05002 and 1,100 mg/L at SW06001.

4.6.1.2 FY89 Sediment Quantity Sampling Results

TSS samples were collected during the spring, fall, and storm sampling events in FY89. Two TSS samples were acquired in the spring and storm events directly into a sample container. Three TSS samples obtained in the fall were acquired with a DH-48 hand-held sampler. Instantaneous discharge measurements were also taken in conjunction with the TSS sampling at most of the sampling sites. Results of the TSS analysis, performed by DataChem Laboratories are summarized in Table 4.6-1.

TSS concentrations were below detection limits in four of the nine samples collected. Two samples, South Plants water tower pond (SW01002) and the Sewage Treatment Plant (SW24001), obtained during the spring sampling had TSS concentrations below the CRL (4.00 mg/l). For samples collected during storms, TSS concentrations were 5.00 mg/l at North First Creek monitoring station (SW24002), 52.0 mg/l at South First Creek monitoring station (SW08003), 62.0 mg/l at Uvalda Ditch D (SW12002) and 672 mg/l at the Motor Pool (SW04001). During the fall sampling, TSS concentrations were below the CRL (4.00 mg/l) at two of three sites along the southern reach of First Creek. The single detection of 5.00 mg/l was measured at SW08004 in First Creek near the habitat pond, where First Creek flow ended at this time of year.

4.6.2 SEDIMENT QUALITY

4.6.2.1 FY88 Sediment Quality Sampling Results

Suspended and bed load sediment samples were obtained for chemical analysis as part of the FY88 stream sediment sampling program. The quantity of suspended sediment samples collected with the DH-48 was insufficient to perform any chemical analysis. An attempt was made to collect mobile bed load sediment samples using the Wilder server sampler. For 30 minutes at each site, the sampler collected primarily algae and minor amounts of sediment. The quantity of the bed load samples collected with a shovel was

Table 4.6-1 FY89 Total Suspended Solids Analytical Results

Sampling Location	Location Name	Sampling Event*	Date	Total Suspended Solids (mg/l)	Flow Rate (cfs)
Irondale Gulch Drainage Basin					
SW01002	South Plants Water Tower Pond	Spring	05/18/89	<4.00	Stagnant
SW12002	Uvalda Ditch D	Storm	05/15/89	62.0	Moderate flow
First Creek Drainage Basin					
SW08001	South First Creek Boundary	Fall	09/29/89	<4.00	0.14
SW08003	South First Creek	Storm	05/14/89	52.0	6.40
		Fall	09/29/89	<4.00	0.10
SW08004	South First Creek (N)	Fall	09/29/89	5.00	0.04
SW24001	Sewage Treatment Plant	Spring	04/21/89	<4.00	0.006
SW24002	North First Creek	Storm	05/15/89	5.00	3.35
Sand Creek Drainage Basin					
SW04001	Motor Pool	Storm	05/15/89	672	Moderate flow

cfs = cubic feet per second
mg/l = milligrams per liter
< = below detection limits

* Spring - April 18 through May 18, 1989
Storm - May 10 through May 15, 1989
Fall - September 25 through September 28, 1989

sufficient to perform chemical analysis. A summary of the compounds detected in the sediment samples is in Table 4.6-2.

Table 4.6-2 FY88 Detected Sediment Organic and Inorganic Compounds

Site #	Analyte Detected	Results
SW05002	Dichlorodiphenyltrichololoroethane	0.0182 μg/L
SW05002	Zinc	12.3 μg/L
SW06001	Dichlorodiphenyltrichololoroethane	0.0373 μg/L
SW08001	Dichlorodiphenyltrichololoroethane	0.0118 μg/L
SW08001	Zinc	31.9 μg/L
SW37002	Arsenic	7.17 μg/L
SW37002	Dieldrin	0.37 μg/L
SW37002	Zinc	11.8 μg/L

4.6.2.2 FY89 Sediment Quality Sampling

Stream bottom or bed load sediment samples were collected at 17 sites during spring sampling and at five sample locations during the fall. The distributions of target organic compound and trace inorganic constituent detections during the spring and fall 1989 sampling are discussed below. The minimum concentrations reported in this section are for concentrations that exceed the CRL. Target organic compound detections are summarized in Table 4.6-3, and target trace inorganic compound detections are summarized in Table 4.6-4.

4.6.2.3 First Creek Drainage

4.6.2.3.1 Organic Compounds in Stream-Bottom Sediments

Stream-bottom sediment samples were collected during FY89 in the First Creek drainage basin locations SW08001, SW08003, SW24002, SW30002, SW31002 and SW37001. Although six organic compounds were detected in stream-bottom sediment samples, only atrazine and CPMSO were detected at two or more locations. Additionally, sediment target organic compound detections were generally not directly related to surface-water detections. Atrazine was detected in stream-bottom sediment from all

Table 4.6-3 FY89 Target Organic Compound Detections in Stream Bottom Sediment Samples (Page 1 of 2)

Sampling Location	Sampling Event*	Compound	Concentration (µg/g)
<u>Irondale Gulch Drainage Basin</u>			
SW01001	Spring	Atrazine	1.00
SW01002	Spring	Aldrin	8.40
		DBCP	0.029
		Dieldrin	0.400
		Isodrin	0.280
		PPDDE	0.061
		PPDDT	0.160
SW02006	Spring	Atrazine	6.23
		DBCP	0.020
	Fall	BTZ	3.55
		Aldrin	3.00
		Dieldrin	3.50
		Endrin	0.280
		Isodrin	0.060
W07001	Spring	Atrazine	2.94
		DBCP	0.014
SW11001	Spring	111TCE	0.336
		Atrazine	4.58
		CPMSO	35.0
		DBCP	0.023
		Toluene	0.375
SW11002	Spring	Atrazine	3.72
		CPMSO	5.94
SW12003	Spring	Atrazine	0.885
		CPMSO	23.8
SW12004	Spring	Atrazine	12.0
		CPMSO	390
		Parathion	0.472
		Vapona	3.80
SW12005	Spring	Atrazine	3.00
		CPMSO	>20.0
	Fall	Dieldrin	0.007
		DMMP	0.534

Table 4.6-3 FY89 Target Organic Compound Detections in Stream Bottom Sediment Samples (Page 2 of 2)

Sampling Location	Sampling Event*	Compound	Concentration (µg/g)
<u>First Creek Drainage Basin</u>			
SW08001	Spring	Atrazine	2.29
		CPMSO	6.88
SW08003	Spring	Atrazine	10.3
		Fluoroacetic acid	9.40
	Fall	Dieldrin	0.032
SW30002	Spring	Atrazine	15.7
		CPMSO	5.40
SW31001	Spring	Atrazine	4.55
		Dieldrin	0.019
		Endrin	0.019
SW31002	Spring	Atrazine	0.303
		Vapona	0.388
SW37001	Spring	Atrazine	3.42
<u>South Platte Drainage Basin</u>			
SW36001	Spring	m-Xylene	0.949
		Atrazine	13.0
		Benzene	0.281
		Chlorobenzene	10.7
		DBCP	0.170
		Ethylbenzene	0.580
		Tetrachloroethene	1.00
		Toluene	0.561
		Xylenes (o,p)	2.10
	Fall	Aldrin	37.0
		Dieldrin	18.0
		Endrin	18.0
		Isodrin	3.30

* Spring - April 18 through May 18, 1989
Fall - September 25 through September 28, 1989
µg/g = micrograms per gram

Table 4.6-4 FY89 Trace Inorganic Constituent Detections in Stream Bottom Sediment Samples (Page 1 of 2)

Sampling Location	Sampling Event*	Compound	Concentration (µg/g)
<u>Irondale Gulch Drainage Basin</u>			
SW01001	Spring	Zinc	27.4
SW02006	Spring	Chromium	13.7
		Copper	78.8
		Mercury	8.00
		Lead	74.7
		Zinc	159
	Fall	Mercury	4.90
SW07001	Spring	Copper	17.5
		Lead	32.2
		Zinc	63.4
SW11001	Spring	Chromium	9.99
		Copper	14.5
		Lead	27.4
		Zinc	102
SW11002	Spring	Lead	18.1
		Zinc	64.7
SW12003	Spring	Arsenic	4.67
		Cadmium	1.71
		Chromium	15.9
		Copper	19.2
		Lead	119
		Zinc	77.5
SW12004	Spring	Copper	12.0
		Lead	37.0
		Zinc	89.2
SW12005	Spring	Zinc	56.1
	Fall	Arsenic	1.23

Table 4.6-4 FY89 Trace Inorganic Constituent Detections in Stream Bottom Sediment Samples (Page 2 of 2)

Sampling Location	Sampling Event*	Compound	Concentration ($\mu g/g$)
First Creek Drainage Basin			
SW08001	Spring	Zinc	22.4
SW24002	Spring	Chromium	12.8
		Copper	11.5
		Lead	19.9
		Zinc	45.4
SW31001	Spring	Chromium	11.8
		Copper	10.5
		Zinc	43.2
SW31002	Spring	Chromium	13.1
		Copper	11.7
		Lead	18.7
		Zinc	49.4
SW37001	Spring	Copper	9.11
		Zinc	41.2
South Platte Drainage Basin			
SW36001	Spring	Arsenic	44
		Cadmium	1.93
		Copper	12.9
		Mercury	0.500
		Lead	103
		Zinc	60.1
	Fall	Mercury	0.570
		Arsenic	19

* Spring - April 18 through May 18, 1989
Fall - September 25 through September 28, 1989
$\mu g/g$ = micrograms per gram

locations except North First Creek monitoring station (SW24002). The only surface-water detection of atrazine was at First Creek Off-Post monitoring station (SW37001). CPMSO was detected in sediment samples from SW08001 and SW30002 but was not detected in surface-water samples from these locations. Dieldrin was detected in sediment samples collected from SW08003 and SW31001, but was detected only in a surface-water sample collected during the same sampling event.

4.6.2.3.2 Metals in Stream-Bottom Sediments

Five locations along First Creek had detections of metals in samples from the stream-bottom sediment along. Chromium, copper, lead and zinc were detected most frequently in the sediment samples.

Zinc was the only trace metal detected in a sample from South First Creek Boundary (SW08001; 22.4 μg/g). Zinc was also detected at concentrations exceeding 22.4 μg/g at North First Creek monitoring station (SW24002), First Creek Toxic Yard A (SW31001), First Creek Toxic Yard B (SW31002) and First Creek Off-Post monitoring station (SW37001).

Chromium, copper, and lead were detected in downstream samples. Chromium was detected in samples from SW24002, SW31001 and SW31002. Copper was detected in samples from SW31001, SW31002 and SW37001. Lead was detected in samples from SW24002 and SW31002.

The detections of trace metals in stream-bottom sediment samples do not correlate with trace metals detected in surface water collected along First Creek. Arsenic was the trace metal detected most frequently in surface water, and zinc was the trace metal detected most frequently in stream-bottom sediment.

4.6.2.4 Irondale Gulch Drainage Basin

4.6.2.4.1 Organic Compounds in Stream-Bottom Sediments

Stream-bottom sediment was collected from nine of 17 locations within the Irondale Gulch drainage basin during the spring sampling of FY89. Sediment was collected from locations SW01001, SW01002, SW02006, SW07001, SW11001, SW11002, SW12003, SW12004 and SW12005.

Although organochlorine pesticides were detected in several surface-water samples collected during spring sampling of FY89, they were not detected in stream-bottom sediment collected at the southern RMA boundary.

The organophosphorus compound atrazine was detected in stream-bottom sediment collected from five locations — Uvalda Ditch A (SW07001), Peoria Interceptor monitoring station (SW11001), Havana Interceptor monitoring station (SW11002), the Storm Sewer (SW12004) and South Uvalda monitoring station (SW12005) — near the southern RMA boundary during spring sampling. Atrazine was not detected in surface water collected at these locations during the spring sampling. The only detection of atrazine in surface water near the southern RMA boundary in FY89 was reported for the Storm Sewer location (SW12004) during the fall sampling.

DMMP was detected only in stream-bottom sediment obtained at the South Uvalda monitoring station (SW12005) during the fall sampling. There was no corresponding detection in the surface-water sample from this location.

Vapona and parathion were detected in stream-bottom sediment from the Storm Sewer (SW12004) during the spring sampling. Vapona was also detected in surface water from this location, but the detection was during the fall sampling.

CPMSO, DBCP, 111TCE and toluene were detected in stream-bottom sediment near the southern RMA boundary in FY89. CPMSO was detected in stream-bottom sediment from four locations, and DBCP was detected in stream-bottom sediment from one location near the southern RMA boundary, the Peoria Interceptor monitoring station (SW11001). Comparison of detections in sediment to detections in surface water from southern RMA boundary locations indicates that CPMSO detected in surface water from the Storm Sewer (SW12004) is the only similar occurrence of these compounds between surface-water and stream-bottom sediment samples. Historical surface-water detections presented in Table 4.3-1 indicate that 111TCE has been detected in surface water from the Peoria Interceptor monitoring station (SW11001) in two of six historical samples.

Stream-bottom sediment collected from the South Plants Lakes area contained atrazine and CPMSO. Atrazine was detected in stream-bottom sediment from the North Uvalda monitoring station (SW01001). Atrazine and CPMSO were detected in stream-bottom sediment from the Rod and Gun Club Pond

(SW12003). In both cases, there was no corresponding occurrence of these compounds in surface water from the South Plants Lakes area in FY89.

Stream-bottom sediment samples were collected from two South Plants area locations in FY89. Most of the contaminants detected in stream-bottom sediment from the South Plants water tower pond (SW01002) were also detected in surface water from this location. At the South Plants steam effluent (SW02006), atrazine and DBCP were detected in stream-bottom sediment from the spring sampling event, and aldrin, dieldrin, endrin, isodrin, and BTZ were detected in stream-bottom sediment from the fall sampling. There were no corresponding detections of these compounds in surface water from this location.

4.6.2.4.2 Trace Metals in Stream-Bottom Sediments

Analytical results for metals detected in stream-bottom sediment from four sampling locations (SW07001, SW11001, SW11002 and SW12005) of spring sampling have been integrated to establish sediment-quality baseline levels. The baseline for arsenic was established from fall sampling data.

Detected concentrations of metals in samples from locations in the Irondale Gulch drainage basin were compared with the established sediment-quality baseline levels. Samples collected from three locations (SW02006, SW12003 and SW12004) contained elevated concentrations of trace metals.

Stream-bottom sediment from the South Plants steam effluent (SW02006) contained elevated concentrations of chromium, copper, mercury, lead and zinc. Stream-bottom sediment from the Rod and Gun Club Pond (SW12003) contained elevated concentrations of arsenic, cadmium, chromium, copper, lead and zinc. Stream-bottom sediment from the Storm Sewer (SW12004) contained elevated concentrations of lead.

In general, the detections of trace metals in stream-bottom sediment do not correlate with detections of trace metals in surface water from the Irondale Gulch drainage basin. Arsenic, mercury and zinc were the most frequently detected trace metals in surface water, and the heavier metals (chromium, cadmium and lead) were detected most frequently in sediment.

4.6.2.5 South Platte Drainage Basin

4.6.2.5.1 Organic Compounds in Stream-Bottom Sediments

Nine organic compounds were detected in stream-bottom sediment collected at the Basin A monitoring station (SW36001) during spring sampling. These nine compounds were also detected at higher concentrations in a surface water sample from this location. Four organic compounds were detected in stream-bottom sediment collected from this location during fall sampling. These four compounds, at lower concentrations, were also detected in surface water collected at this location at the same time.

4.6.2.5.2 Trace Metals in Stream-Bottom Sediments

Stream-bottom sediment collected at the Basin A monitoring station (SW36001) contained elevated concentrations of arsenic, cadmium, mercury, and lead.

4.7 PRE-CMP SURFACE-WATER/GROUNDWATER INTERACTION DATA ASSESSMENT

The interactions between groundwater and surface water at RMA have been recognized in previous studies. RCI conducted the first surface-water hydrologic investigation at RMA using data derived from other sources (RCI, 1982). Precipitation records from Stapleton Airport and Brighton, Colorado were used in the study. Surface-water hydrologic analysis on areas south of the Arsenal was also used. An overall view on groundwater and aquifer characteristics was provided in reports by Geraghty and Miller (Stollar and Van der Leeden, 1981), and Romero and Ward (1981). A memo supplied by Shell Chemical Company provided monthly data on lake volumes, potable water entering the lakes, water received via Highline Canal, water delivered to other parts of the Arsenal, and makeup process water.

One objective of this initial investigation was to evaluate the potential for calculating an Arsenal-wide water balance. Basin A, the South Plants Lakes and Highline Lateral were studied and a semi-quantitative analysis was performed. Several other surface-water bodies on RMA were investigated with conclusions of losing or gaining conditions based on field observations and assumptions. Overall sources of groundwater recharge were evaluated and it was concluded that very little, if any, recharge to ground water at RMA is derived from precipitation in vegetated areas. The water balance conducted on the South Plants Lakes (Ladora, Upper Derby, and Lower Derby) indicated a potential recharge to ground water, but conditions could vary depending on lake levels. It was also noted that Havana Pond was probably recharging groundwater. Measured flow at two points on Highline Lateral suggested surface-

water loss through infiltration. A visual inspection of First Creek indicated that there were significant infiltration losses throughout the channel. Field observations along the Uvalda Interceptor indicated that water in portions of the ditch was an expression of the water table. The water balance calculated for Basin A was approximated using available literature because no inflow or storage volume relationship data were established.

This initial evaluation indicated that several more gaging stations would greatly assist in quantifying gain-loss relationships for surface-water bodies on RMA. A subsequent report (RCI, 1983) presented the results of a new water balance for Upper Derby, Lower Derby, and Ladora Lakes. Six recording stream gages had been installed by RCI in the spring of 1982. The rating curves for most of the stream gages were empirical. A water balance for June through September 1982 was prepared using the new stream gaging data. Preliminary data suggested recharge to groundwater from channels entering the Arsenal. The initial assessment that recharge to groundwater was occurring from the South Plants Lakes appeared to be consistent with the new water balance analysis. At this preliminary stage of baseline data collection, all conclusions were considered tentative.

Surface-water monitoring results for October 1982 through September 1983 were described in a September 1984 report (RCI, 1984). The goal of establishing a quantitative year-round water balance record for the South Plants Lakes was not achieved. Problems with calculations were related to incomplete water inventory data. Records provided by RMA personnel regarding the amount of potable water released to the lakes were not well defined. Also, lake volumes did not agree with the measured stage data. Incomplete stream gaging data for inflow to the lakes created additional data gaps in water inventory records. Other sources of water input to the lakes included precipitation, as calculated using data recorded at Stapleton Airport. Water removed from the lakes was calculated based on pan evaporation data from Cherry Creek Reservoir. Because of the amount of missing or estimated data, no conclusions were drawn for this period concerning groundwater/lake interaction in the South Plants area.

Surface-water data for October 1, 1985 through September 30, 1986 continued to be collected by RCI on subcontract to ESE. Results of the gaging program and water balance calculations for the period were in two reports. The initial presentation of the data were in December 1986 in Annual Surface-Water Data Report, Rocky Mountain Arsenal, October 1, 1985 - September 30, 1986. This information was later recompiled, revised, and presented by ESE (Appendix F; Ebasco, et al, 1989a). Unaccountable gains or losses for the surface-water bodies were reported in acre-feet. These values were used to infer

groundwater recharge or discharge from the surface-water bodies. The water balance calculations for the six areas investigated showed that: 1) Havana Pond showed a consistent unaccountable loss of water each month, 2) Upper and Lower Derby Lakes showed unaccountable water loss for all recorded months except April, 3) Ladora Lake had unaccountable gains for all months except February, 4) First Creek (between the north and south on-post gaging stations) generally showed a water loss between May and September and water gain from October to April, 5) Uvalda Interceptor (between the north and south gaging stations) showed a net unaccountable water loss for all months except November, December and September, 6) Lake Mary displayed intermittent gain and loss over the 12-month monitoring period.

In 1989, final results of the RI programs at RMA were published in the WRI report (Ebasco, et al, 1989a). Surface-water data collected between October 1985 and September 1987 was compiled and reviewed. One objective of the WRI report was to identify and quantify the interactions between surface water and groundwater at RMA. Study areas were: Upper Derby Lake, Lower Derby Lake, Ladora Lake, Lake Mary, Havana Pond, Basin A, Basin B through E, Basin F, Uvalda Interceptor, Highline Lateral, the STP, First Creek and North Bog. The principal data used for evaluating groundwater/surface-water interactions for these study units were monitoring well-water level data (i.e., groundwater elevation data) surface-water monitoring data (i.e., discharge data, stage and volume data, surface-water elevation data) and climatic data (i.e., precipitation and evaporation). Quantitative evaluations of gain-loss were based on water balance calculations. Discharge and recharge rates between certain surface-water bodies and groundwater were also calculated. Results of this study are summarized in Table 4.7-1.

4.8 CMP Groundwater/Surface-Water Interaction Assessment

The methodology used to assess surface-water and groundwater interactions was presented in Section 3.8.2. The discussion of the assessment has been divided into sections for the First Creek drainage basin (4.8.1) the South Plants Lakes area and the Irondale Gulch drainage basin (4.8.2) with specific reference to Havana Pond and the Uvalda Interceptor.

4.8.1 First Creek Drainage Basin

During FY88 the interactions between groundwater and First Creek were assessed using limited data. A comparison of thalweg slope to April water-table elevations showed First Creek both gained (effluent)

Table 4.7-1 Summary of Groundwater/Surface-Water Interaction Data (Page 1 of 3)

Location	WRI Report		
	Recharge to Groundwater	Discharged to by Groundwater	Information Used
Upper Derby Lake	X - When lake is full	X - When lake is below stage measurements	• 1 groundwater well hydrograph compared to lake level • Water balance calculations
Lower Derby Lake	X		• 4 groundwater well hydrographs compared to lake level hydrograph • Water balance calculations
Ladora Lake		X	• 6 groundwater well hydrographs compared to lake level hydrograph • Water balance calculations
Lake Mary		X	• 6 groundwater well hydrographs compared to lake level hydrograph • Water balance calculations
Havana Pond	X		• 3 groundwater well hydrographs compared to pond level hydrograph • Water balance calculations
Uvalda Interceptor	X - between South and North Uvalda Gaging stations		• 3 groundwater well hydrographs compared to South Uvalda stage measurements • Water balance calculations

Table 4.7-1 Summary of Groundwater/Surface-Water Interaction Data (Page 2 of 3)

Location	WRI Report		
	Recharge to Groundwater	Discharged to by Groundwater	Information Used
First Creek On-Post	X		• Water balance calculations
North First Creek Off-Post		X	• Comparison of stream bed and water-table elevations • Water balance calculations • Water quality data
Basin A Drainage			• 5 upgradient and 7 downgradient monitoring wells. • Surface-water elevations compared to groundwater elevations. • Water quality compared between surface-water and groundwater samples. • Water balance calculations.
- lime settling basins	X		
- Central pool		X	
Basin A Drainage			
- Basin B	X - When high surface-water accumulations are present in the basin.	X - based on upgradient monitoring well water level fluctuations.	• 3 upgradient wells and 1 downgradient monitoring well. • Surface elevations compared to groundwater well hydrographs.
- Basin C	X - indeterminate because of deep groundwater table		• 2 upgradient monitoring wells and 4 downgradient wells. • Surface-elevations compared to water table elevations.

Table 4.7-1 Summary of Groundwater/Surface-Water Interaction Data (Page 3 of 3)

Location	WRI Report		
	Recharge to Groundwater	Discharged to by Groundwater	Information Used
- Basins D and E			• Basins generally dry. Insignificant area of surface water/groundwater interchange.
- Basin F (prior to interim response action)			• 6 downgradient monitoring wells. Regression analysis to compare relationship between precipitation and groundwater levels. No apparent interaction between basin liquids and groundwater.
Highline Lateral	X		• Monitoring well water level elevations compared to surface water elevations.
Sewage Treatment Plant Discharge Ditch	X - not a significant source		• 4 monitoring wells. • Reviewed water table elevations in area of the discharge ditch. • Compared water quality in ditch discharge water to groundwater chemistry in vicinity of the ditch.

and lost (influent) water along certain sections of the stream. The relationships were determined to be seasonal, and variable according to groundwater levels and flow characteristics. Major ion and inorganic chemistry was also computed between First Creek and ground water along a limited reach of the stream. This analysis showed groundwater discharged to First Creek north of RMA under low flow.

Data were assessed from monitoring wells and surface-water sampling locations in the First Creek drainage basin by comparing major ion chemistry data and organic compound detections at surface-water and groundwater sampling locations. From data collected in Section 31 on RMA, Stiff diagrams constructed from the analytical results for surface- and groundwater samples from Well 31016 (Figure 3.8.1) and SW31001 (First Creek Toxic Yard A) indicate that these waters are characterized as sodium carbonate (Figure 4.8-1).

In Section 24, the Stiff diagram constructed from analysis of an alluvial groundwater sample from Well 24188 is different from Stiff diagrams constructed from the analysis of surface-water samples collected near SW24002. Groundwater collected from this well contained high concentrations of sodium and sulfate. Upstream of this well, surface water is characterized as sodium carbonate; downstream of this well, surface water is characterized as sodium 1 sulfate. The RMA sewage treatment plant discharges to First Creek in the vicinity of Well 24188; however, analysis of this discharge water (SW24001) indicated relatively low concentrations of sodium and sulfate.

Alluvial groundwater and surface water along First Creek north of RMA exhibit similar chemical characteristics. Stiff diagrams constructed from the analysis of Wells 37343 and SW37001 (First Creek Off-Post monitoring station) characterized waters as sodium sulfate (Figure 4.8-1). In addition, the occurrence and concentrations of organic contaminants in samples from these locations are similar (Table 4.8-1). The organic contaminants chlordane, DCPD, DIMP, dieldrin, endrin and PPDDT were detected in both surface water and groundwater collected from these locations during spring FY89.

Due to the lack of sufficient monitoring wells close to First Creek, a hydrographic analysis of groundwater and surface-water interaction could not be performed.

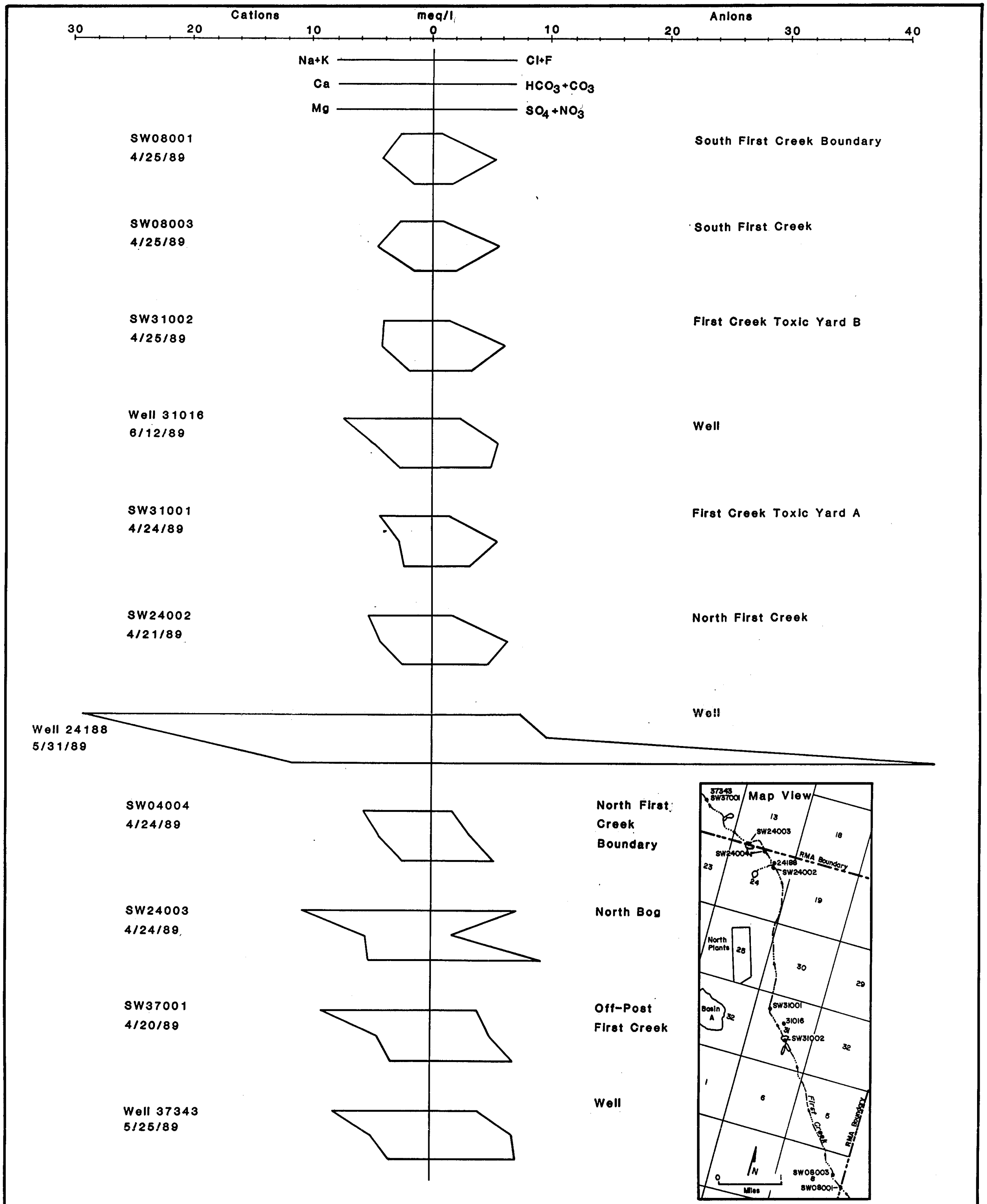


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Figure 4.8-1

Surface-Water and Ground-Water Stiff Diagrams for the First Creek Drainage

CMP SW FY90 H

A gain-loss study was conducted between sampling locations SW08001 and SW37001 (Figure 3.8-1) on September 29, 1989. Discharge measurements indicated a net loss along this section of the stream. It was noted, however, that First Creek is both a gaining or losing stream, depending on the season. Generally, First Creek is influent from July through October, and is effluent from November through June.

4.8.2 IRONDALE GULCH DRAINAGE BASIN

Surface-water and groundwater hydrograph data compiled during the first year of the CMP indicated that Havana Pond, portions of Lower Derby Lake, western Ladora Lake, and northwestern Lake Mary recharged the groundwater system. Hydrograph data also indicated that southeastern Lower Derby Lake, eastern Ladora Lake and southeastern Lake Mary received recharge from groundwater.

A comparison of water chemistry and water levels was used to analyze surface-water/groundwater interactions in FY89 for selected surface-water bodies in the Irondale Gulch drainage basin.

From a comparison of the major ion chemistry and organic compounds in samples of surface water and groundwater in the South Plants Lakes area, the surface water from Upper Derby Lake and Lower Derby Lake and groundwater from Well 01074 (Figure 4.8-2) are characterized as sodium/calcium carbonate. However, Denver Formation water from nearby Well 01047 and alluvial groundwater from Well 01073 are characterized as sodium sulfate and sodium carbonate, respectively. A water sample from Well 02059, which appears to be downgradient of Lower Derby Lake, is characterized as calcium carbonate. Well 02060, screened in the Denver Formation at the same location as Well 02059, is sodium carbonate.

The waters of samples from Ladora Lake, Lake Mary and upgradient Well 02034 is sodium carbonate. However, a sample from Well 02034 contained several organic compounds not detected in lake samples. Downgradient of Ladora Lake, groundwater samples from Wells 02055 and 02056 are characterized as calcium carbonate. This chemistry differs from water samples from Ladora Lake, which are sodium carbonate.

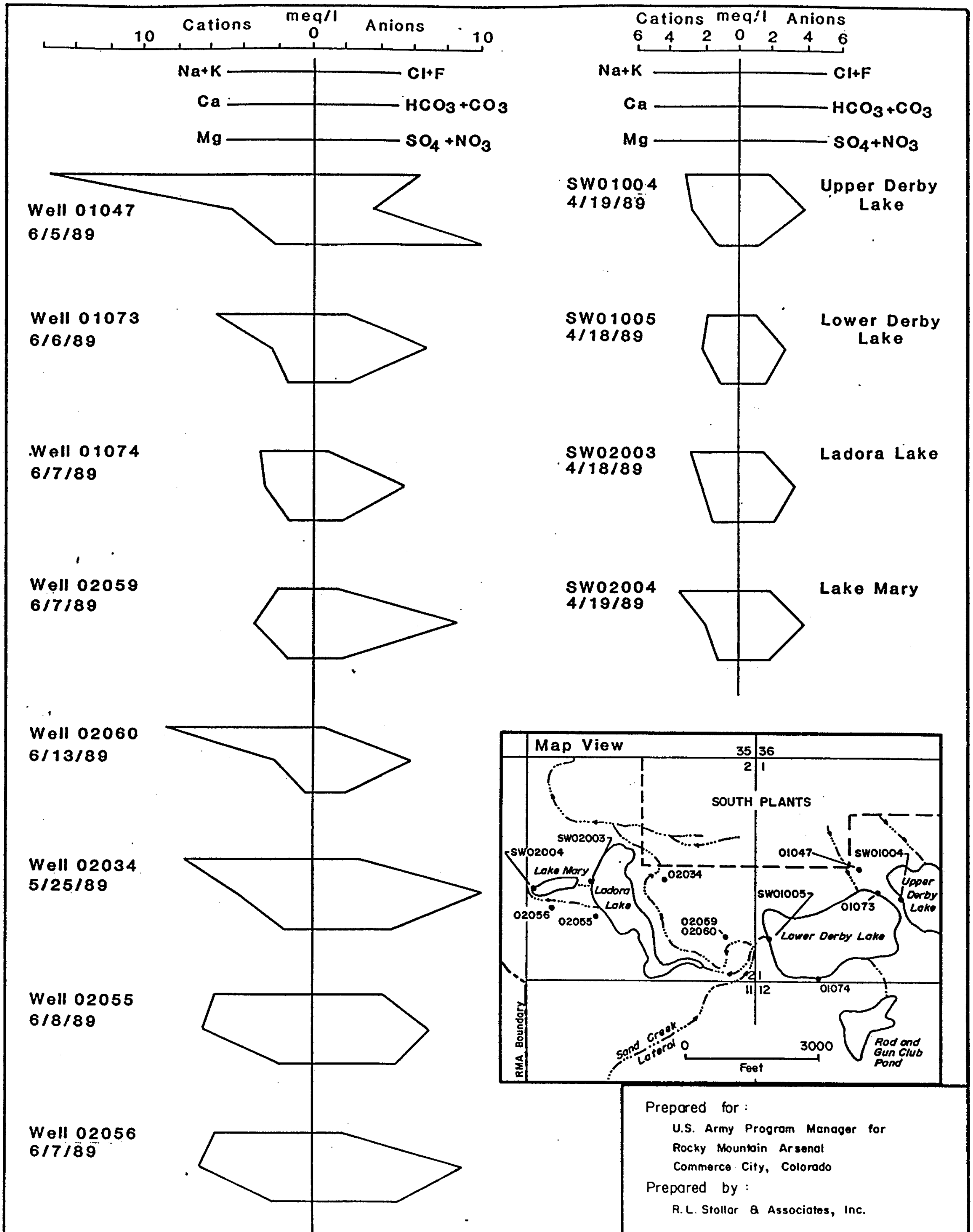

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Figure 4.8-2

Surface-Water and Ground-Water Stiff Diagrams for the South Plants Lakes Area

CMP SW FY90 H

Table 4.8-1 Comparison of Surface-Water and Groundwater Organic Compound Detections for Spring FY89 (Page 1 of 2)

Surface-Water Site			Groundwater Site		
Sampling Location	Compound	Concentration (µg/l)	Sampling Location	Compound	Concentration (µg/l)
First Creek Drainage Basin					
SW31001	ND		SW31016	CHCL3	0.628
SW31002	ND			CHC6H5	3.05
SW242002	Vapona	0.660	SW24188	DIMP	4.36
SW24004	ND				
SW37001	Chlordane	0.268	SW37343	Chlordane	0.612
	DCPD	21.1		DCPD	10.5
	DIMP	88.0		DIMP	140
	Dieldrin	0.0577		Dieldrin	0.112
	Endrin	0.0643		Endrin	0.179
	PPDDT	0.0571		PPDDT	0.263
	Atrazine	9.59		CHC6H5	1.03
Irondale Gulch Drainage Basin, South Plants Lakes Area					
SW01004	Endrin	0.0533	SW01073	ND	
SW01005	ND		SW01074	ND	
			SW02059	ND	
			SW02060	ND	
			SW01047	Xylenes (o,p)	1.91
				CHCL3	3.64
				DIMP	4.34
SW02003	ND		SW02034	11DCLE	2.65
SW02004	Isodrin	0.0972			
				Aldrin	0.683
				Benzene	6.17
				CHCL3	8.37
				DIMP	1.29
				Dieldrin	0.205
				Endrin	0.154
				Isodrin	0.361
				PPDDT	0.385
				Parathion	1.63
				Supona	1.97
				TCLEE	1.54
				TRCLE	3.02

Table 4.8-1 Comparison of Surface-Water and Groundwater Organic Compound Detections for Spring FY89 (Page 2 of 2)

Surface-Water Site			Groundwater Site		
Sampling Location	Compound	Concentration (μg/l)	Sampling Location	Compound	Concentration (μg/l)
			SW02055	ND	
			SW02056	ND	

μg/l = micrograms per liter
ND = No detections of organic compounds

Groundwater and surface-water interaction is indicated by water levels of Havana Pond, Upper Derby Lake, Lower Derby Lake, Ladora Lake, Lake Mary and proximal wells. Havana Pond appears to be recharging groundwater to the north but due to the lack of monitoring wells the relationship in the other directions is unknown. In the Upper Derby Lake, Lower Derby Lake, Ladora Lake and Lake Mary areas, groundwater appears to be discharging to the lakes from the east-southeast, and the lakes appear to be recharging the groundwater toward the west-northwest. Near the east side of Ladora Lake, the water levels indicate that the upward direction of groundwater flow is from the Denver Formation (Well 02060) through the alluvium (Well 02059) to the lake.

Gain-loss flow measurements were taken on South Uvalda Interceptor between sampling sites SW12005 and SW12009 on September 29, 1988. A decrease in flow was recorded between these two points, but historically the South Uvalda gaging station records (Table 4.2-1) indicate year-round flow. This suggests South Uvalda can be influent between the stream-flow measurement locations, but a baseflow is maintained by groundwater discharge.

5.0 REFERENCES

American Public Health Association et al., 1985. Standard Methods for the Examination of Water and Wastewater, 16th Edition.

Anderson, B.L., Project Engineer, Environmental Engineering Division RMA, 1980, September. Personal Communication.

Blackwell, P.A., 1973, August. Army Material Command Contamination Survey, Rocky Mountain Arsenal, Colorado. U.S. Army Technical Escort Center.
RIC#81339R20

Bureau of Reclamation, 1974. Water Measurement Manual - A Manual Pertaining Primarily to Measurement of Water for Irrigation Projects. U.S. Department of the Interior, Denver, Colorado.

CAPS (Colorado Aerial Photo Service) 1986, October 16. Negative No. 10, Order Number 8587.

Clark, J., Assistant Project Manager, U.S. Army RIC Center, Commerce City, Colorado. Personal Communication, 1989, December 14.

Ebasco Services, Inc., 1987a, July. Final Phase I, Contamination Assessment Report, Site 24-6, Sewage Treatment Plant. Version 3.2.

Ebasco Services, Inc., 1987b, May. Contamination Assessment Report, Site 6-2, Eastern Upper Derby Lake (Upper Derby Lake Overflow). Phase I, Final, Version 3.2.

Ebasco Services, Inc., 1987c, June. Contamination Assessment Report, Site 1-2 Upper and Lower Derby Lakes. Phase I, Final, Version 3.2.

Ebasco Services, Inc., 1987d, July. Final Phase I Contamination Assessment Report: Site 24-6, Sewage Treatment Plant, Version 3.2, Task 7.
RIC#87216R08

Ebasco Services, Inc., 1988a, January. Contamination Assessment Report, Site 24-7, North Bog. Phase I, Final, Version 3.1.

Ebasco Services, Inc., 1988b, April. Final Contamination Assessment Report, Sanitary Sewer Interceptor Line. Version 3.2.

Ebasco Services, Inc., 1988c, August. Final Contamination Assessment Report, Process Water System, Version 3.2.

Ebasco Services, Inc., et al., 1989a, July. Final Water Remedial Investigation Report. Version 3.3.

Ebasco Services, Inc., et al., 1989b, May. Proposed Final Remedial Investigation Report, Southern Study Area. Version 3.2.

Ebasco Services, Inc., et al., 1989c, June. Proposed Final Remedial Investigation Report, South Plants Study Area. Version 3.2.

Ebasco Services, Inc., et al., 1989d, June. Proposed Final Remedial Investigation Report, North Plants Study Area. Version 3.2.

Ebasco Services, Inc., et al., 1989e, June. Proposed Final Remedial Investigation Report, Central Study Area. Version 3.2.

Ebasco Services, Inc., et al.,1989f, June. Proposed Final Remedial Investigation Report, North Central Study Area. Version 3.2.

Ebasco Services, Inc., et al., 1989g, May. Proposed Final Remedial Investigation Report, Western Study Area. Version 3.2.

Ebasco Services, Inc., et al.,1989h, May. Proposed Final Remedial Investigation Report, Eastern Study Area. Version 3.2.

Ebasco Services, Inc., et al., 1989i, May. Proposed Final Remedial Investigation Report, Southern Study Area. Version 3.2.

ESE, Inc., 1985b, Rocky Mountain Arsenal Off-Post Contamination Assessment Technical Plan.

ESE, Inc., 1985c, January. Rocky Mountain Arsenal Section 36 Contamination Survey Draft Technical Plan. Task 1 (Section 36).

ESE, Inc., 1986a, February. Continued Off-Post Groundwater Montioring Program (Revision III - 360 Degree Monitoring Program), Rocky Mountain Arsenal.

ESE, Inc., 1986b, August. Draft Final Source Report, Source 26-5. Task Number 6.

ESE, Inc., 1987a, December. Final Phase I, Contamination Assessment Report, Site 26-3: Basin C. Version 3.3.

ESE, Inc., 1987b, August. Water Quantity/Quality Survey, Final Initial Screening Program Report, Task 4.
RIC#87253R01

ESE, Inc., 1987c, December, Rocky Mountain Arsenal Off-Post Assessment Contamination Assessment Report.
RIC#88343R01

ESE, Inc., 1988a, May. Final Screening Program Third and Fourth Quarters, Final Report (Version 3.1). Water Quantity/Quality Survey, Task 4.

ESE, Inc., 1988b, May. Final Technical Plan, Task 44.

ESE, Inc., 1988c, May. Final Phase I, Contamination Assessment Report, Site 26-6: Basin F Version 3.3.

ESE, Inc., 1988d, March. Water Level and Raingage Charts. October 1, 1985 - December 7, 1987, Volumes I, II, and III. Tasks 4 and 44.

ESE, Inc., 1988e, August. Rocky Mountain Arsenal, Off-Post Operable Unit Remedial Investigation and Chemical Specific Applicable or Relevant and Appropriate Requirements Draft Final Report, Task 39.
RIC#89024R01

Freeze, R.A., and Cherry, J.A., 1979. Groundwater. Prentice-Hall, Inc.

Graaf, R.F. and Reilly, R.T., 1943, June 18. Report on Storage Dams for Process Water. Letter to Area Engineer RMA. MF RMA 305 1679-1682.

Green, James, Chief Facility Engineer, Rocky Mountain Arsenal, Commerce City, Colorado. Personal Communication, 1989.

Guy, H.P. and Norman, V.W., 1970. Field Methods for Measurement of Fluvial Sediment. Techniques of Water-Resources Investigations of the United States Geological Survey: Book 3 Applications of Hydraulics. Washington, D.C.

Hunter/Environmental Science and Engineering (ESE) Inc., 1985a, July. Water Quantity/Quality Survey Draft Technical Plan. Task 4.

Jones, E.G., Chief of Analytical Branch, Laboratory Support Division, PMO RMA, Personal Communication 1980, September.

Knaus, J.H., 1982. Letter from Shell to RMA Commander. Microfilm RSH969, Frame 0548.

Larsh, J.L., 1969, May 22. Storm Drainage Channel Montbello Development, Letter to U.S. Army Corps of Engineers, Omaha District. MF RNA 019 0016 0017.

Moloney, W.J., 1982, February. Assessment of Historical Waste Disposal in Section 36 of Rocky Mountain Arsenal, Colorado.
RIC#82235R02

Morrison-Knudsen Engineers, Inc., (MKE), 1987. Phase I Literature Review Aquatic Resources Investigation, Rocky Mountain Arsenal.

Morrison-Knudson Engineers, Inc., (MKE), 1988, January. Geology of the RMA, Adams County, Colorado, Prepared for Holme, Roberts and Owen, Denver, Colorado.

NOAA, 1989, Local Climatological Data Annual Summary with Comparative Data, Denver, Colorado

NOAA, 1987, Local Climatological Data Annual Summary with Comparative Data, Denver, Colorado

PMCDIR, 1977, March. Installation Assessment of Rocky Mountain Arsenal. Report No. 107.
RIC # 81266R68

PMO (U.S. Army Program Manager's Office for Rocky Mountain Arsenal Cleanup). 1988, March. Final Technical Program Plan FY88-FY92 (Remedial Investigation/Feasibility Study/Interim Response Actions), Volumes I and II.
RIC#88131LR01

Radian Corporation, 1987, October. Contouring and Plotting System for Personal Computer, Version 3.1, Austin, Texas.

Rantz, S.E., 1982. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge; Measurement and Computation of Streamflow: Volume 2. Computation of Discharge. U.S. Geological Survey Water-Supply Paper 2175. Washington, D.C.

Resource Consultants, Inc., (RCI) 1982, March. Surface-Water Hydrologic Analysis, Rocky Mountain Arsenal, Denver, Colorado. Prepared for: Stearns-Rogers Engineering Corporation, Denver, Colorado and USATHAMA, Aberdeen Proving Ground, Maryland.
RIC#82096R01

Resource Consultants, Inc., (RCI) 1983, January Rocky Mountain Arsenal Surface-water Gaging Program, April - November, 1982. Interim Report.

Resource Consultants, Inc., (RCI) 1984, September. Rocky Mountain Arsenal Surface-Water Gaging Program October 1982 - September 1983 Final Report.

Resource Consultants, Inc., (RCI) 1986a, December. Annual Surface-Water Data Report, Rocky Mountain Arsenal, October 1, 1985 - September 30, 1986. Volumes I and II.

Resource Consultants, Inc., (RCI) 1986b. Review and Proposed Revisions of Stage-Volume Curves for Rocky Mountain Arsenal's Lower Lakes.

Resource Consultants, Inc., (RCI) 1987, June. Rocky Mountain Arsenal Concluding Surface-Water Report, Fort Collins, Reference 1330, pp.36

R.L. Stollar & Associates, Inc., (RLSA) 1988, September. Comprehensive Monitoring Program - Draft Final Field Procedures Manual Surface-Water. Version 2.1.

R.L. Stollar & Associates, Inc. et al., (RLSA) 1989a, September. Comprehensive Monitoring Program - Final Technical Plan, Version 3.1.

Romero, John C., and Greg Ward, 1981, Water Table Contour Map of the Rocky Mountain Arsenal Region, Southwest Adams County, Colorado, Hydrologic Investigations Atlas HA-1, Colorado Division of Water Resources, Department of Natural Resources, Denver, Colorado, 1 sheet.

Stearns-Roger Engineering, 1989. Personal Communication, Commerce City, Colorado.

Stollar, Robert L. and Frits van der Leeden, 1981, Evaluation of the Hydrogeologic System and Contamination Migration Patterns, Rocky Mountain Arsenal, Denver, Colorado, Final Report for Contract No. DAAK11-79-C-0148, prepared for USATHAMA, Aberdeen Proving Ground, Maryland (Geraghty & Miller, Soysset, New York), 119 pp + 23 Pates.

Stout, K., and L., Abbott, 1982. Installation Assessment, RMA, Vol. I and II. Brontres Corporation, EPA, and USATHAMA
RIC #83368R01

U.S. Army, Geohydrology Division, 1977. Water Monitoring at Rocky Mountain Arsenal (A Review of 360 Degree Monitoring Program).

U.S. Army, 1989, July. Chemical Quality Assurance Plan, Version 1.0, Rocky Mountain Arsenal, Commerce City, Colorado.

U.S. Army Chemical Warfare Service, 1945. History of Rocky Mountain Arsenal - 1945, RSA 008 0572.

U.S. Army Chemical Warfare Service, 1946. History of Rocky Mountain Arsenal - 1946, RMA 191 0612-1213.

U.S. Army Corps of Engineers, 1953, March 13. Specifications for the Construction of Additional Contaminated Reservoir Capacity, Rocky Mountain Arsenal, Denver, Colorado, Serial No. ENG-25-066-53-164, RMA 057, 1140-1188.

U.S. Army Corps of Engineers, 1982. HEC-2 Water Surface Profiles, User's Manual. The Hydrologic Engineering Center, Davis, California.

U.S. Army Corps of Engineers, 1983a, March. Evaluation of the Existing and Future Flood Potential on the Rocky Mountain Arsenal, Denver, Colorado. U.S. Army Engineer District. Omaha.

U.S. Army Corps of Engineers, 1983b. Inspection Report, Mary Dam and Lake, Rocky Mountain Arsenal, Adams County, Colorado.

U.S. Army Corps of Engineers, 1983c. Inspection Report, Basin C, Rocky Mountain Arsenal, Adams County, Colorado.

U.S. Army Corps of Engineers, 1983d, July. Inspection Report, Havana Street Interceptor Basin, Commerce City, Colorado.

U.S. Army Corps of Engineers, 1984, June. Basic Information Maps. Rocky Mountain Arsenal.

U.S. Army Corps of Engineers, 1987. Annual Inspection Report Lower Derby Dam and Lake, Rocky Mountain Arsenal, Commerce City, Colorado.

U.S. Environmental Protection Agency (EPA), 1988, August 8. CERCLA - Compliance With Other Laws Manual, Draft Guidance.

U.S. Geological Survey (USGS) 1977. National Handbook of Recommended Methods for Water Data Acquisition. Office of Water Data Coordinator, USGS, Reston, Virginia.

Ward, G.J., Physical Science Technician, Laboratory Support Division, PMO RMA, 1990, September. Personal Communication.

Ward, G., 1984. The 360 Degree Monitoring Program, 1983 Review, Rocky Mountain Arsenal, Commerce City, Colorado.
RCI#84088R01

Whitman, et. al., 1943. Rocky Mountain Arsenal Water Supply Facilities, Sanitary Department - Graph of Storage, Area, and Time of Filling for Process Water Storage Lakes. For Kuljian and Co., Engineers. Plan Number 7164-2222.

Wright Water Engineers, Inc., 1988, May. First Creek, Irondale Gulch, and DFA 0055 Outfall Systems Hydrology Report.

Wright-McLaughlin Engineers, 1969, November. Master Plan for Major Drainage, Stapleton International Airport, North of Sand Creek with Emphasis on New North-South Runway and Environs. MF RMA071,2222-2260.